IPET & Risk Assessment Group Effort for LaCPR

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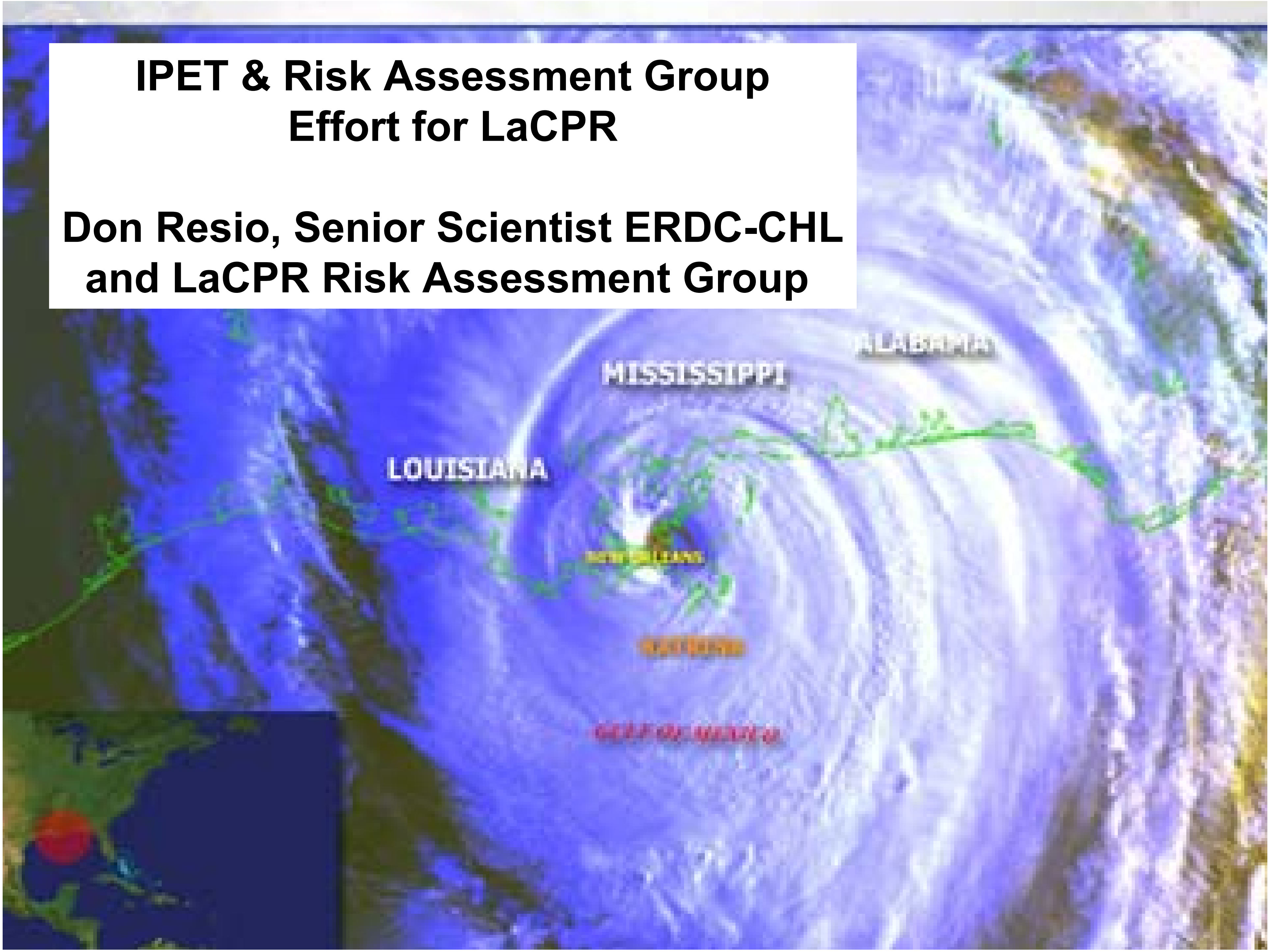
and LaCPR Risk Assessment Group



OUTLINE:

- Brief discussion of IPET findings & risk methodology
- Development of Surge Potential and Storm Ranking
- Characteristics of strong hurricanes in Gulf of Mexico
    - tracks
    - decay during approach to land
    - interrelationships among parameters
- Statistical estimates for risk
    - multivariate probability space
    - single site versus area probabilities
    - return periods of Cp at landfall
- Climatic variability??
- Where we are & Future directions

Some Key IPET findings:

1. Wind fields are of primary importance to accuracy of surge estimates (PBL model + data).

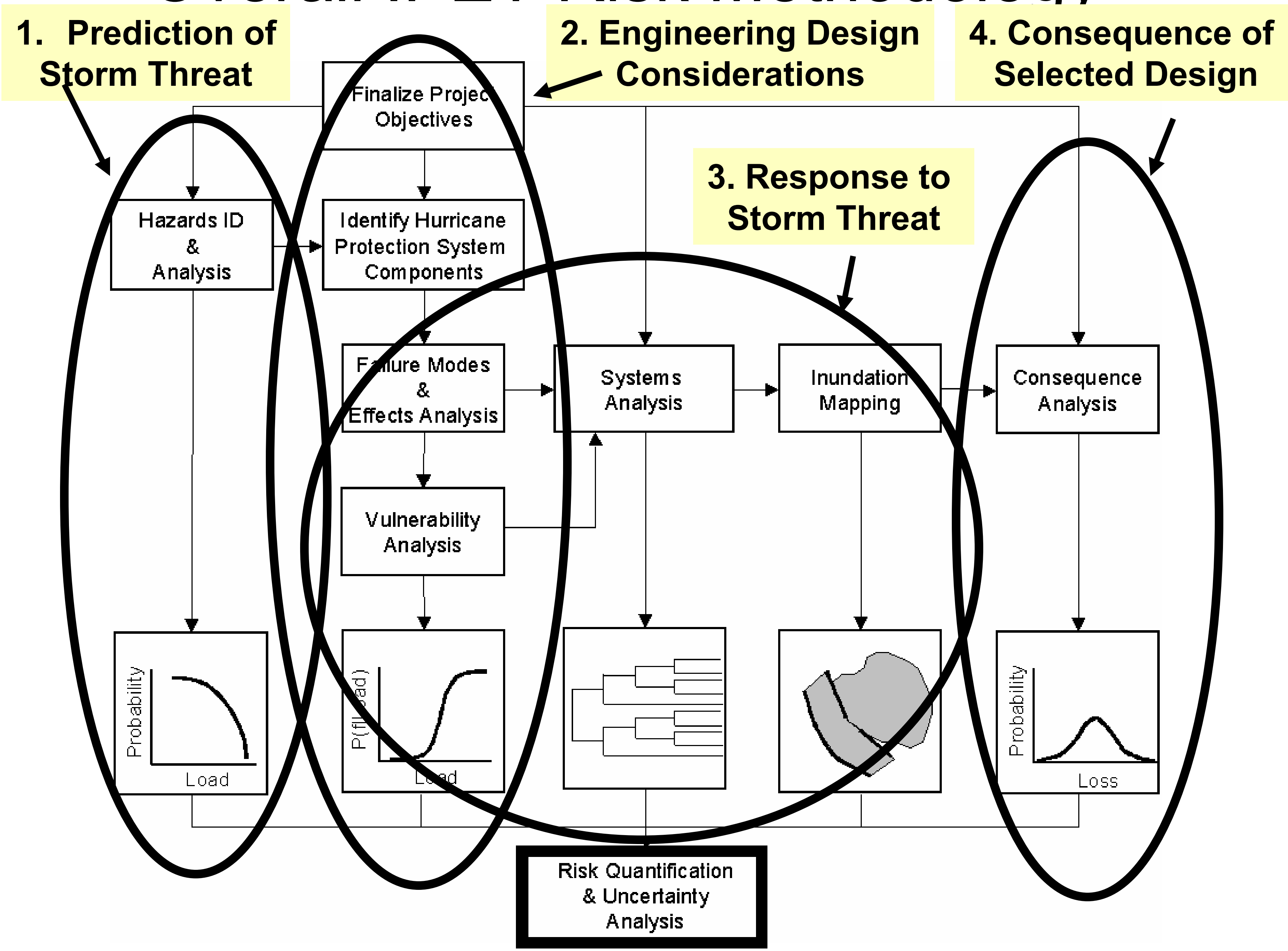
2. Wave contributions to surge could not be neglected or treated within a simplified "surge-model-only" approach.

3. Hurricane Protection System must be a functioning system and not a disjoint set of structures.

4. Risk must be assessed probabilistically

5. Structural response must be treated via careful physics-based approach rather than empirical/ parametric methods.

Overall IPET Risk Methodology



RECENT EXPERIENCE:

IPET – Joint Probability Method (spatial sampling)

18000 storms reduced to only 2000 rough scale and later to only about 600 fine scale runs but details were very crude

EST/FEMA (local data + some smoothing of large storms)

Sampling size is such that 100-year values are questionable for hurricanes.

Should length of record be only factor considered in plotting position for determining CDF?

Given recognized climatic variability and horrible sampling prior to 1940's, why should earlier data be included? This distorts the actual frequency of events from today's data. This might "help" in Katrina direct-hit area but will lead to severe under-prediction of present risk in other areas.

Example of Recent ADCIRC runs for New Orleans Area
46 historical storms selected – 42 runs passed QC (no key storms missing)

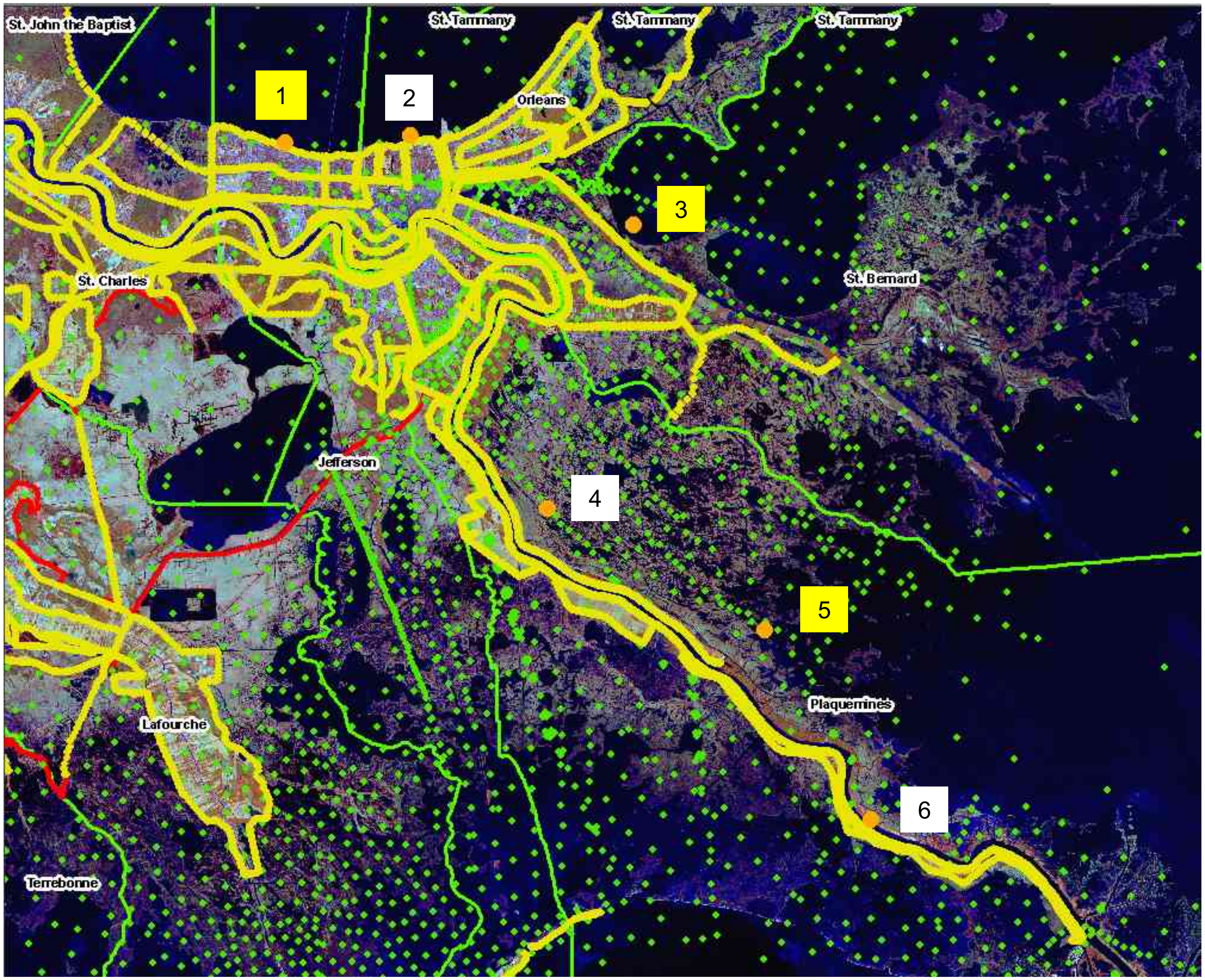
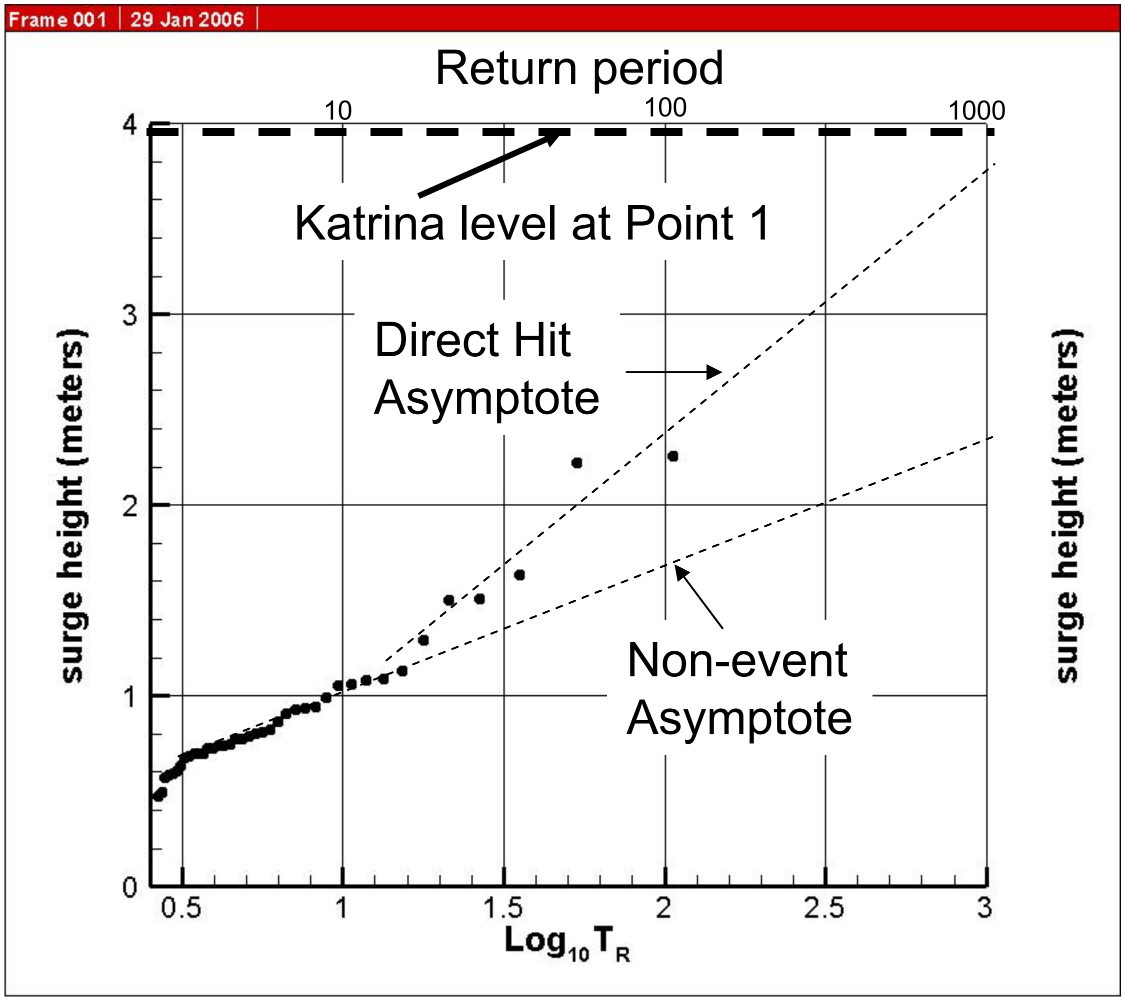


Figure shows points saved that will be discussed highlighted in yellow.

LOG Return Period Plot of ADCIRC Results

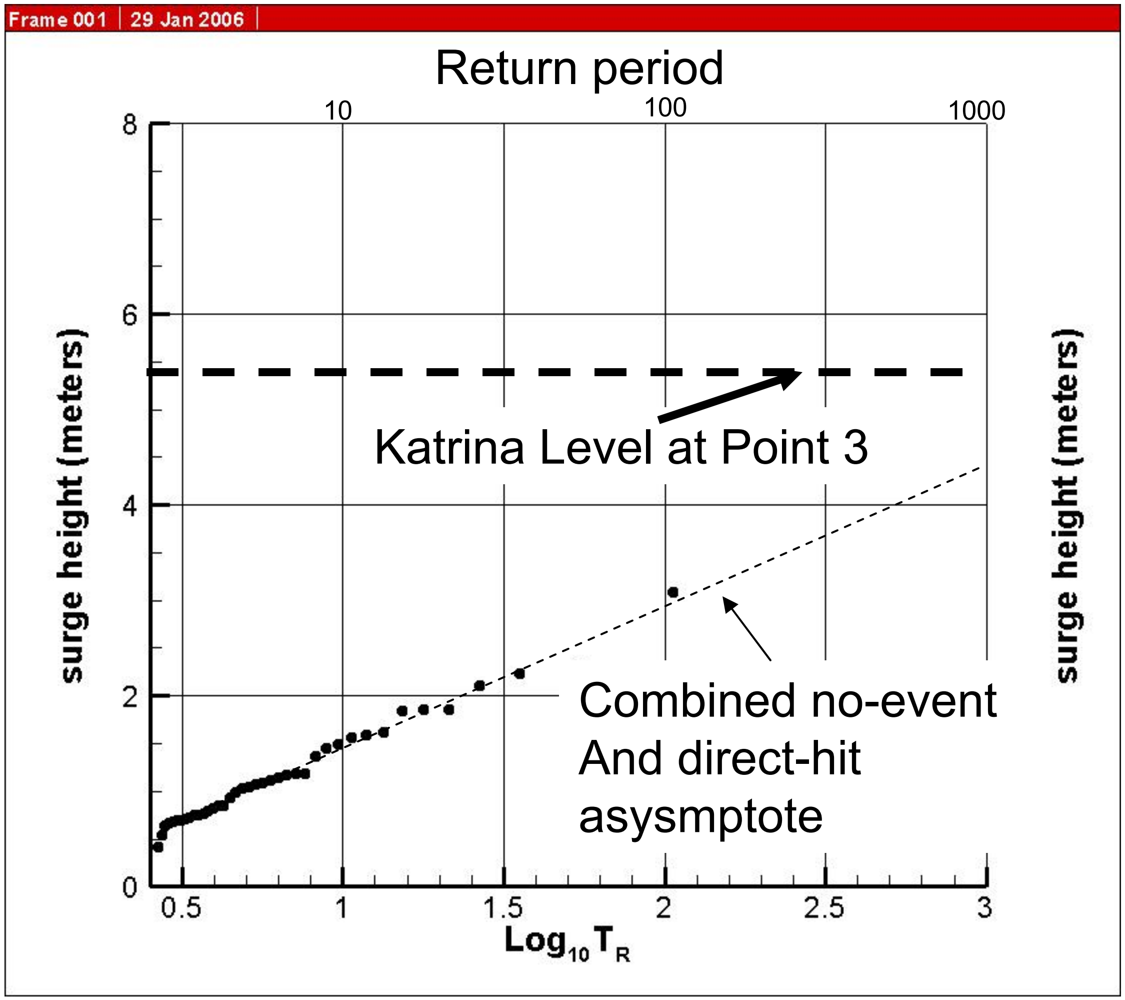
Point 1 (Lake Ponchartrain) – 2005 Hurricanes Removed



Results from FEMA simulations before 2005 storms are added show that Katrina may be a rare event for Lake Pontchartrain

LOG Return Period Plot of ADCIRC Results

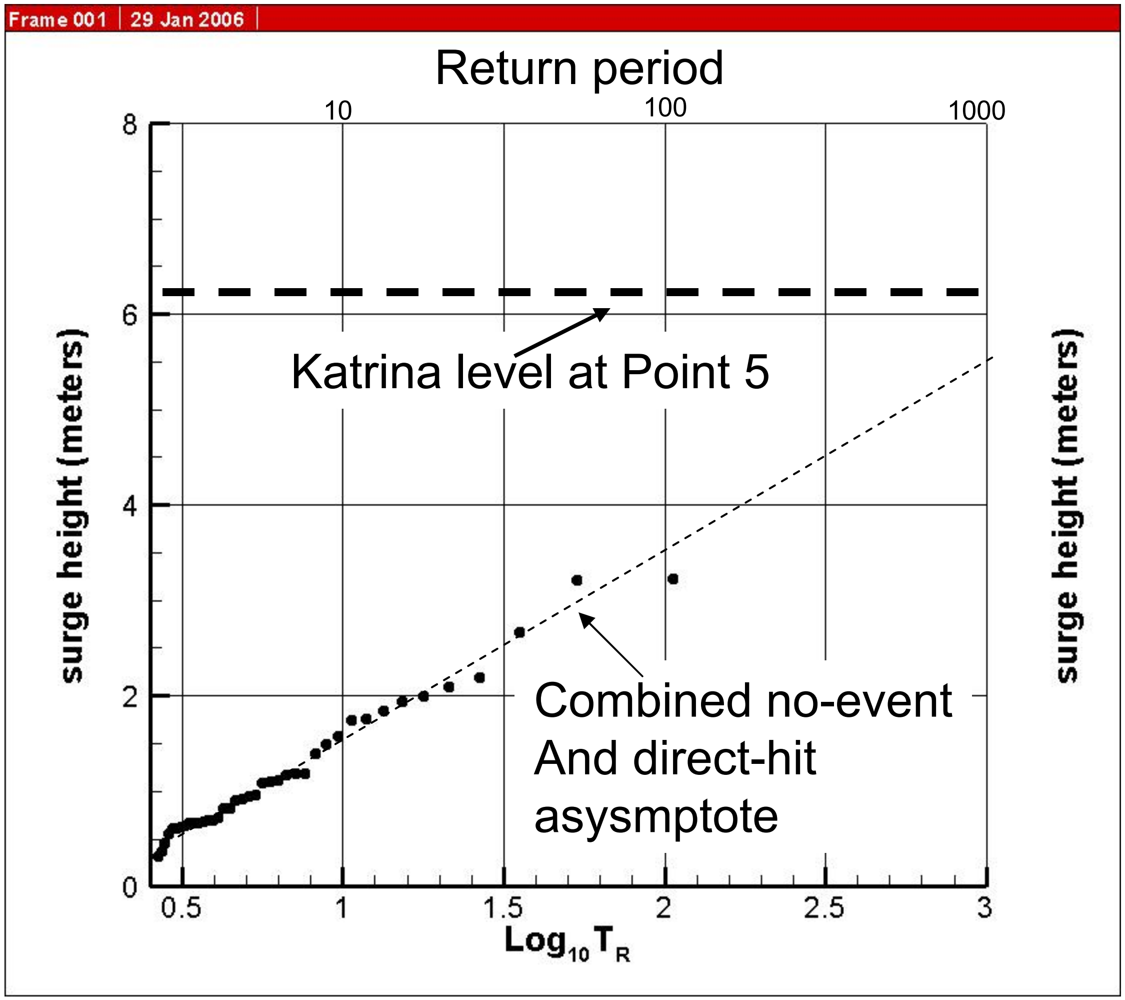
Point 3 (St Bernard Parish) – 2005 Hurricanes Removed



Results from FEMA simulations before 2005 storms are added show that Katrina may be a rare event for St Bernard Parish

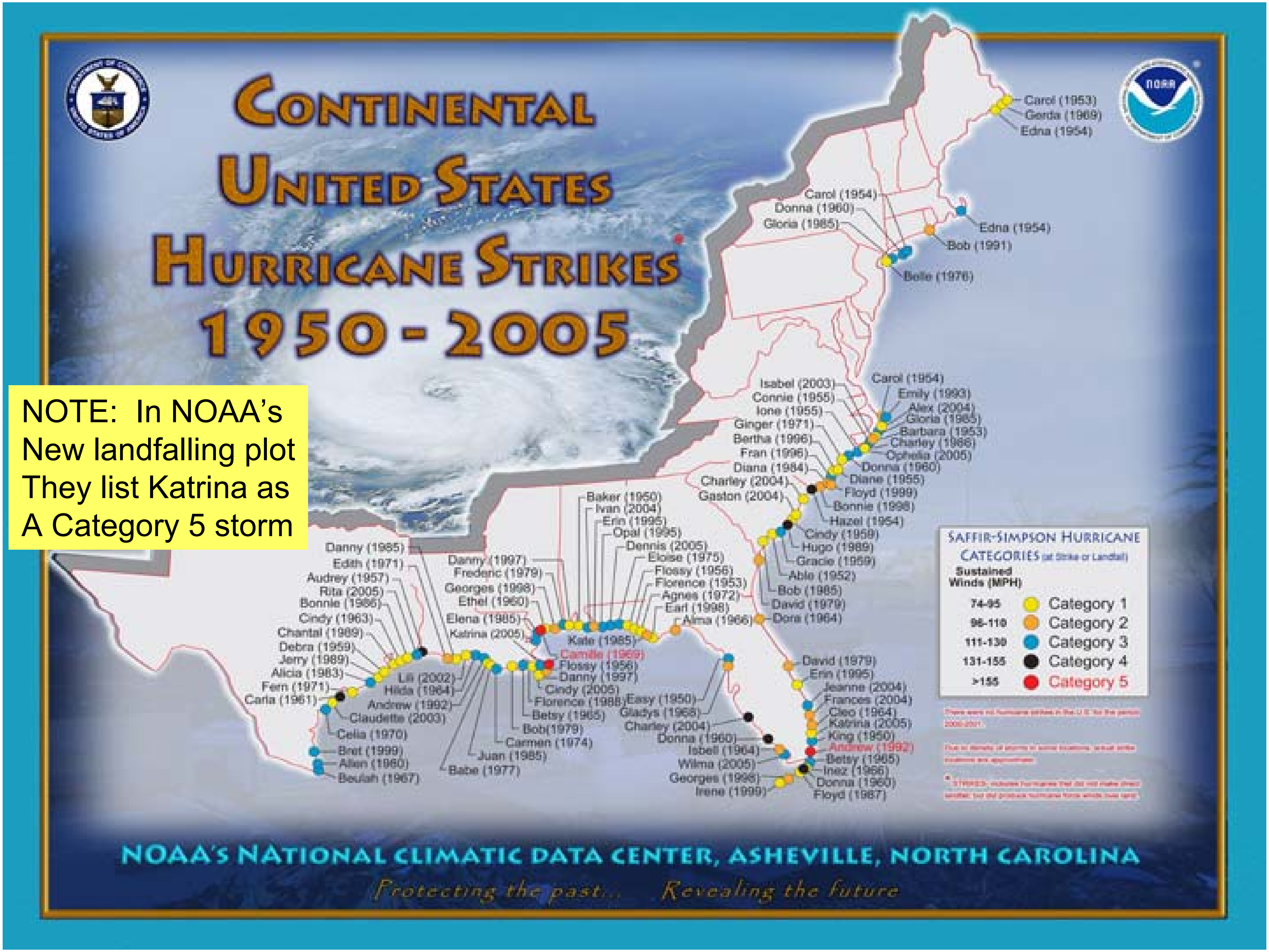
LOG Return Period Plot of ADCIRC Results

Point 6 (Plaquemines Parish) – 2005 Hurricanes Removed

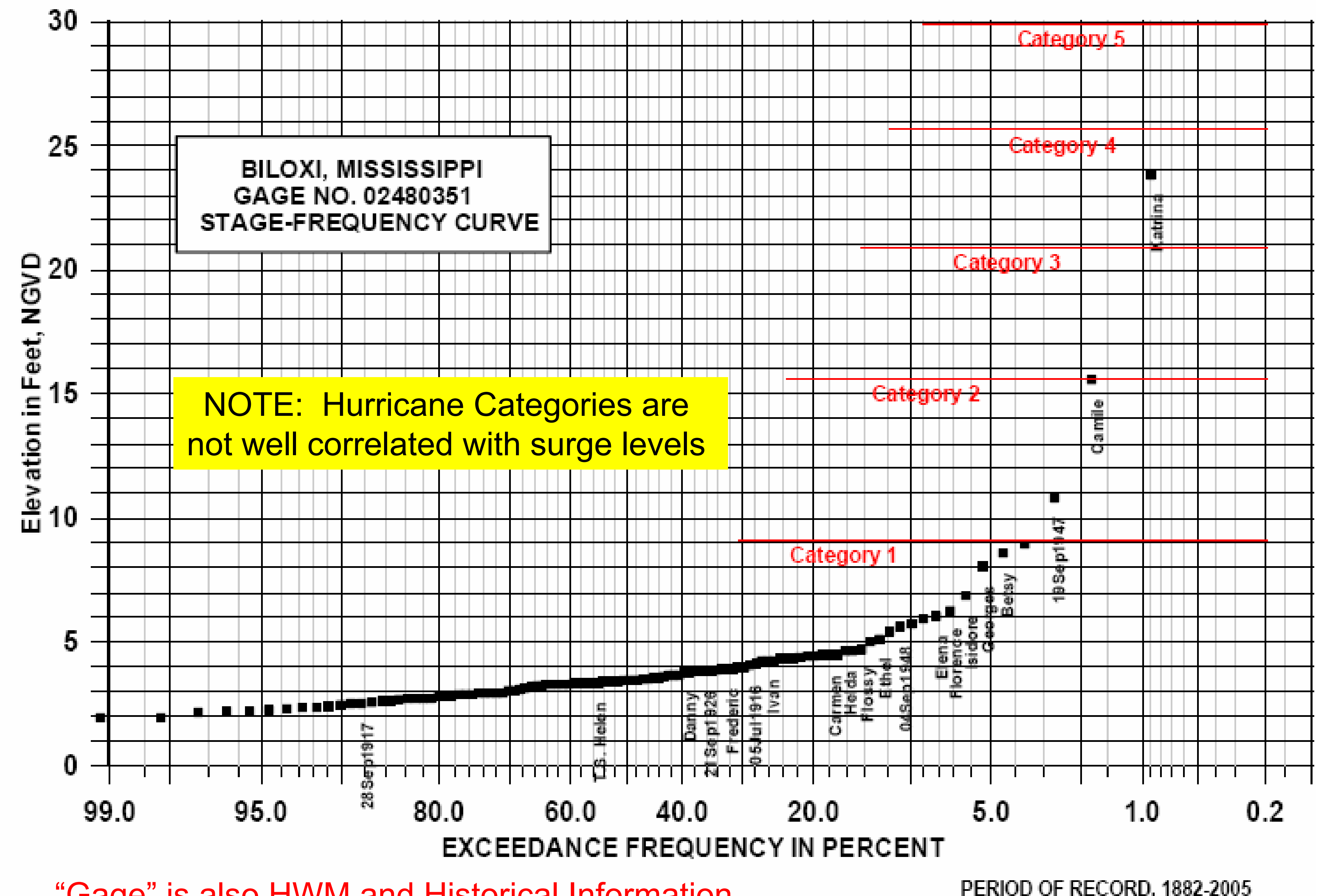


Results from FEMA simulations before 2005 storms are added show that Katrina may be a rare event for Plaquemines Parish

NOTE: In NOAA's
New landfalling plot
They list Katrina as
A Category 5 storm



NOAA Historical Data Analysis with Hypothetical Category Impact Superimposed



"Gage" is also HWM and Historical Information

Characterization of Potential Surge Levels In Hurricanes: Beyond the Saffir-Simpson Scale

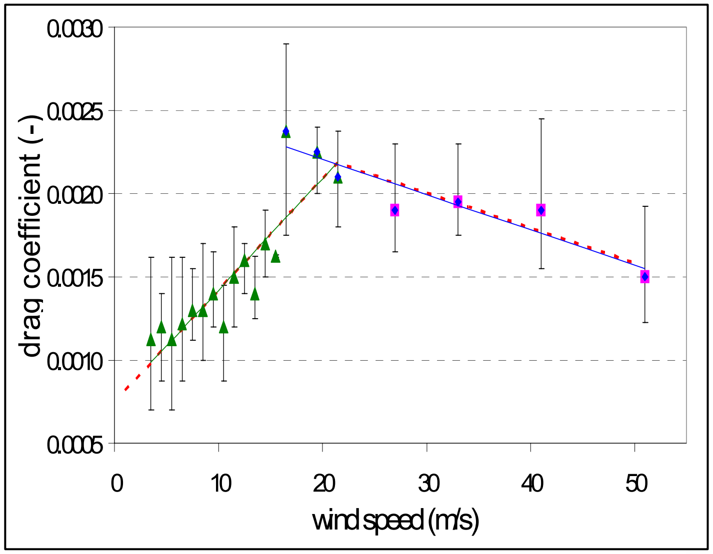
- Use calibrated ADCIRC with validated estimates of wind speeds
- Develop functional relationships that include effects of wind speed, storm size, forward speed of storm, characteristic slope of nearshore/slope region, and distance between site and location of peak surge
- Develop understanding of relationships between offshore hurricane characteristics and landfall characteristics

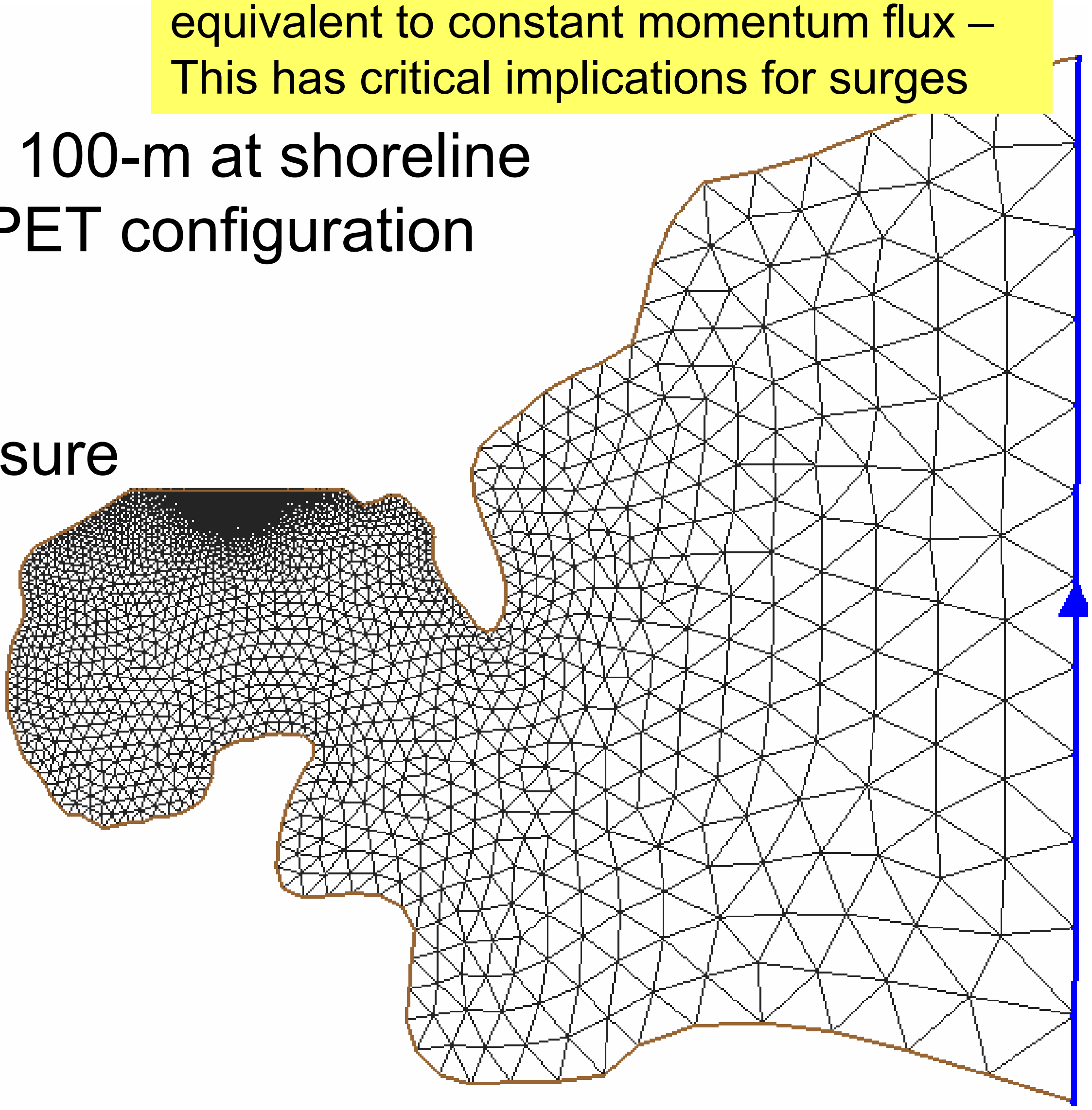
Storm Surge Characterization

Model Setup

NOTE: High wind behavior appears to be equivalent to constant momentum flux – This has critical implications for surges

- ADCIRC
  - Finite element
  - Variable resolution: 100-m at shoreline
  - Calibration: using IPET configuration
  - Forcing:
    - Wind stress
    - Barometric pressure





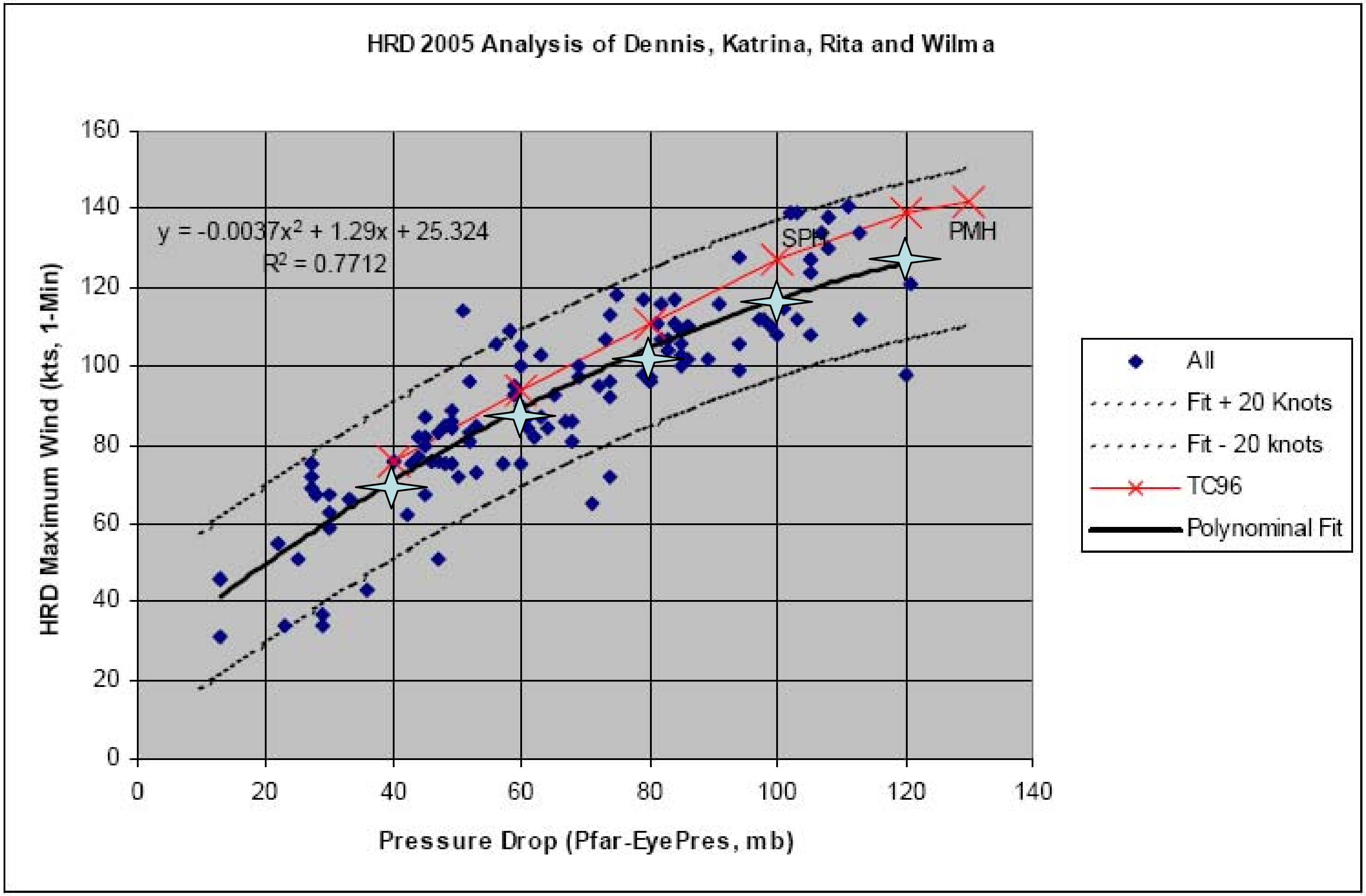
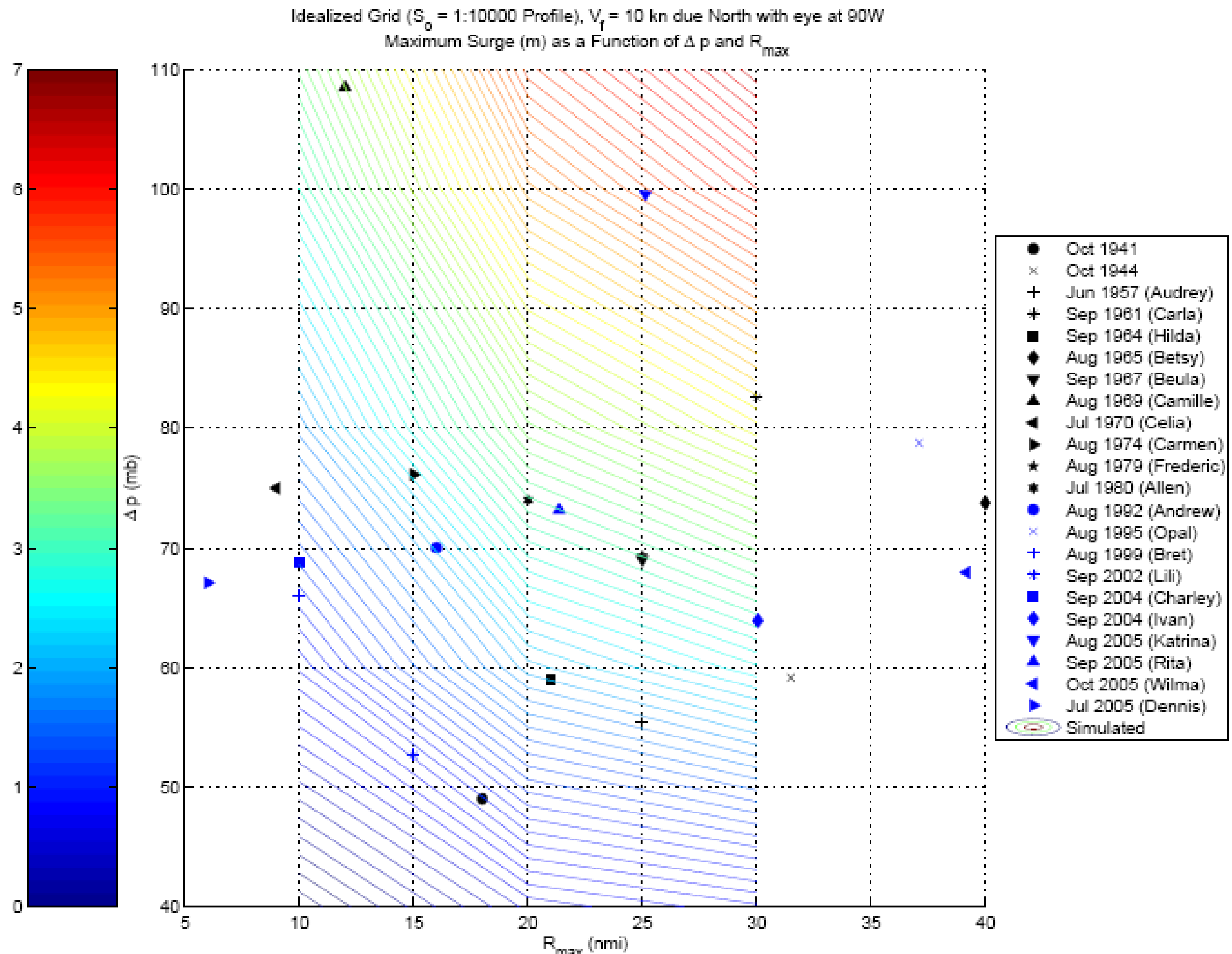


Figure 1. TC96 Maximum 1-minute wind (kts) solution compared with HWind 1-min maximum wind (kts) vs. pressure drop (mb)

$V_{max} = (V_f + (A\Delta p\text{-}B)^{1/2}) \times 1.2$
Note: 1.2 factor converts from 1-min max to 30-min average

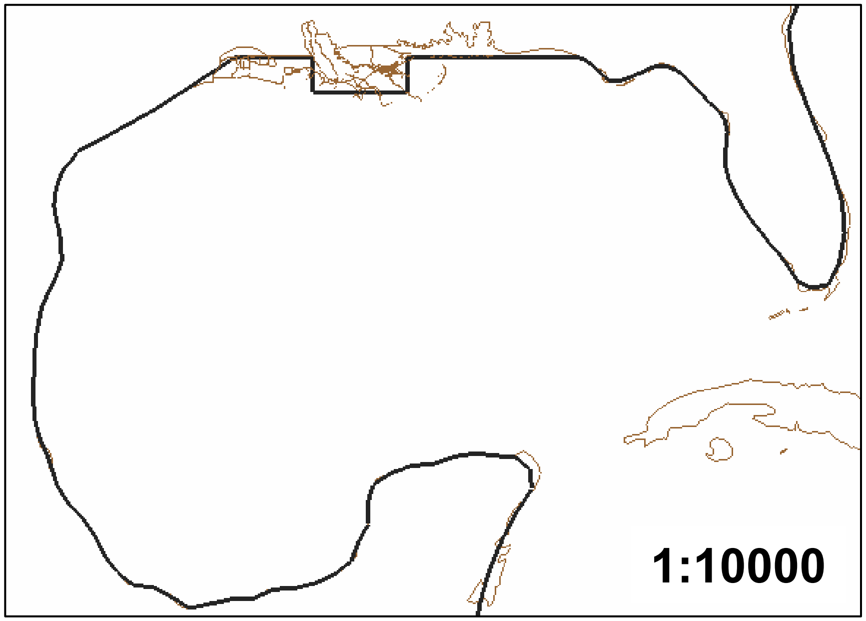
Constant Holland "B" seems ok for first Approximation.

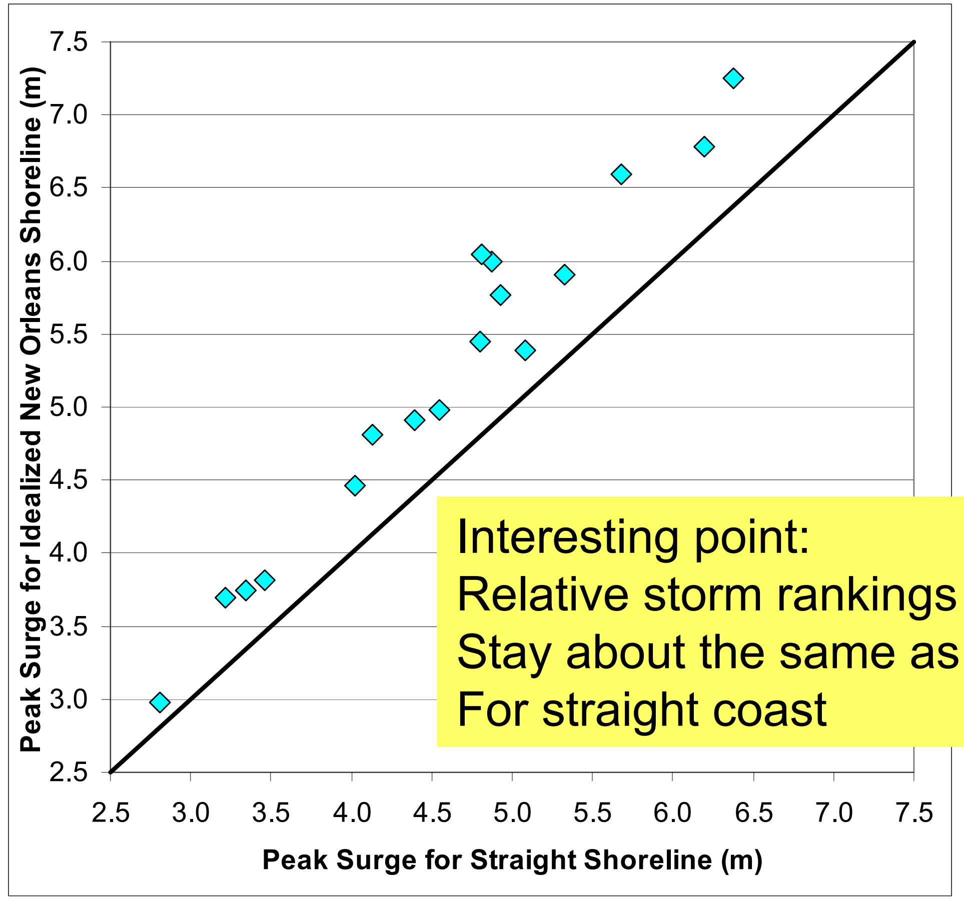


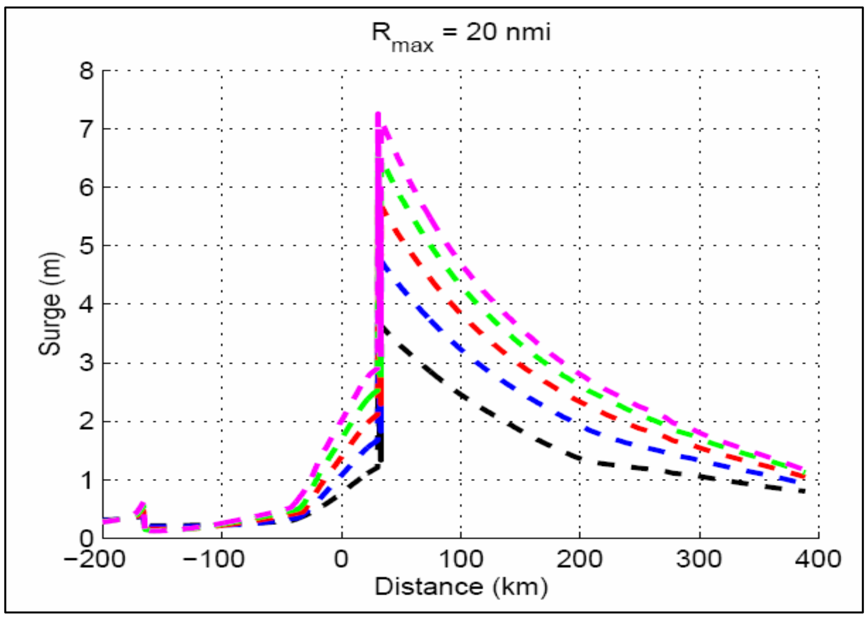
Context of large historical storms in Gulf of Mexico on a slope of 1:10,000

Storm Surge Characterization

Ongoing Work: Shoreline Features



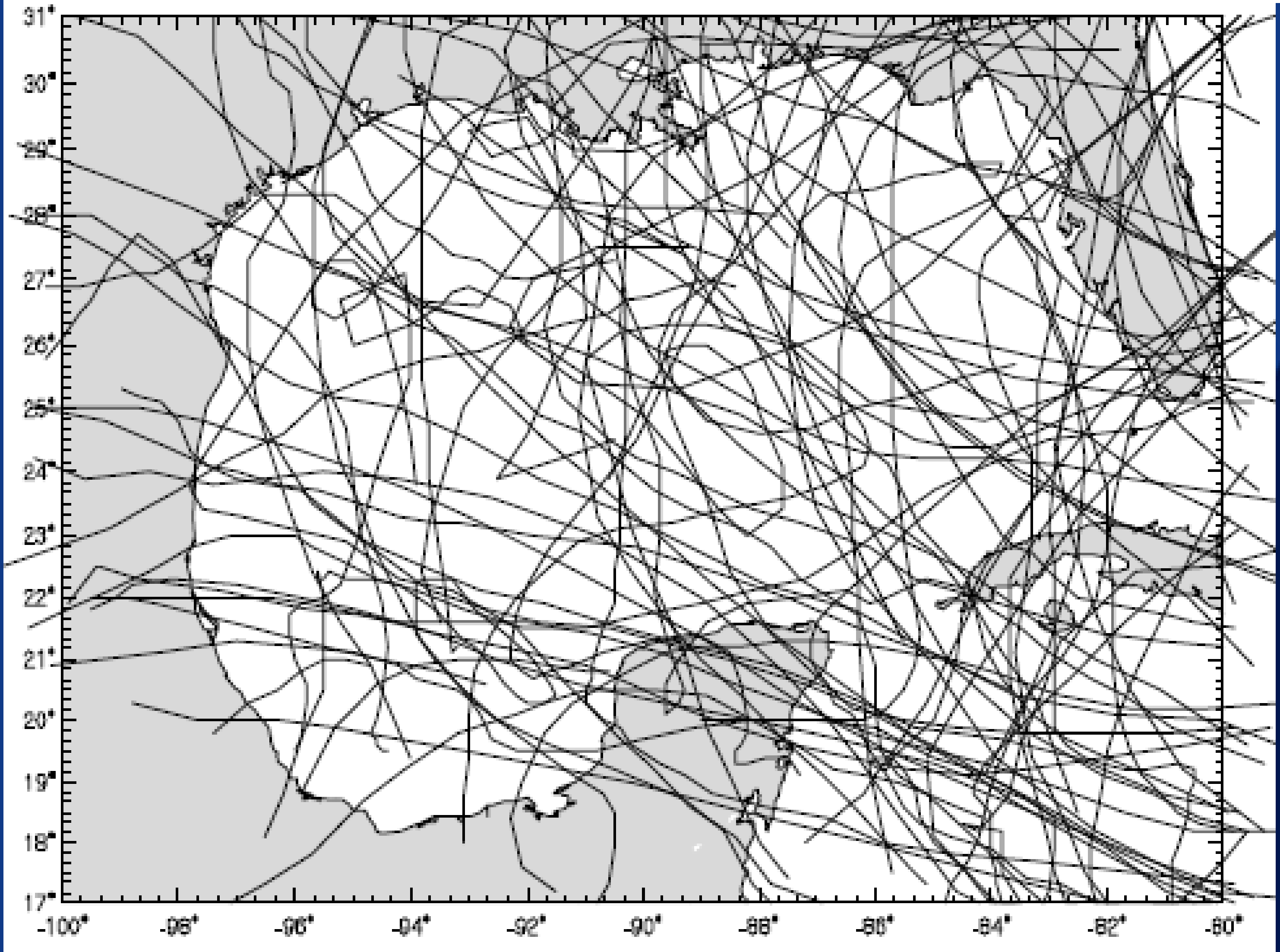


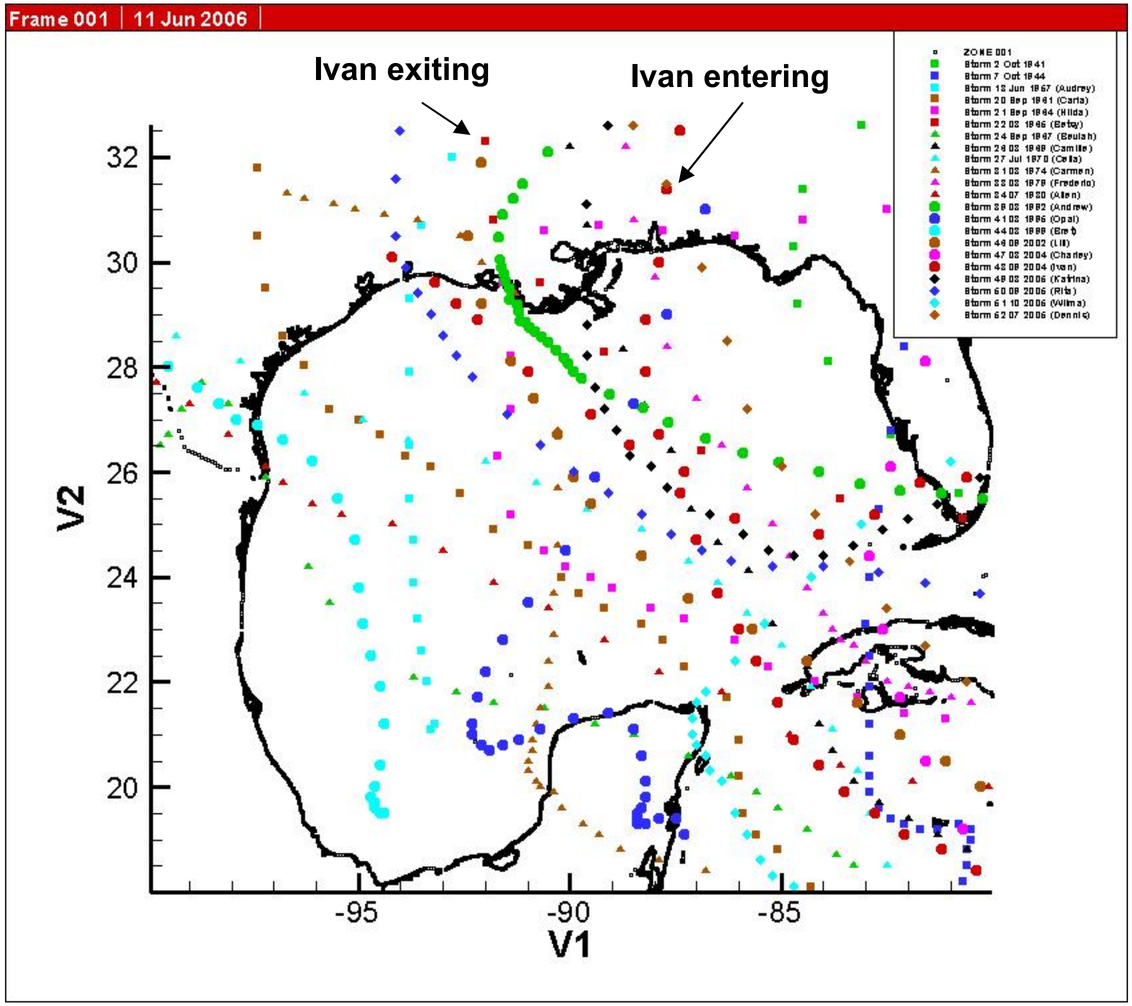


Peak surge ~ 10% larger in area with coastal shape as shown here.

Cat. 2 Candidate Track Map

So where's the pattern in this?





Tracks of all “major” (Cp in Gulf ≤ 955 mb) storms landfalling in Gulf of Mexico 1941-2005.

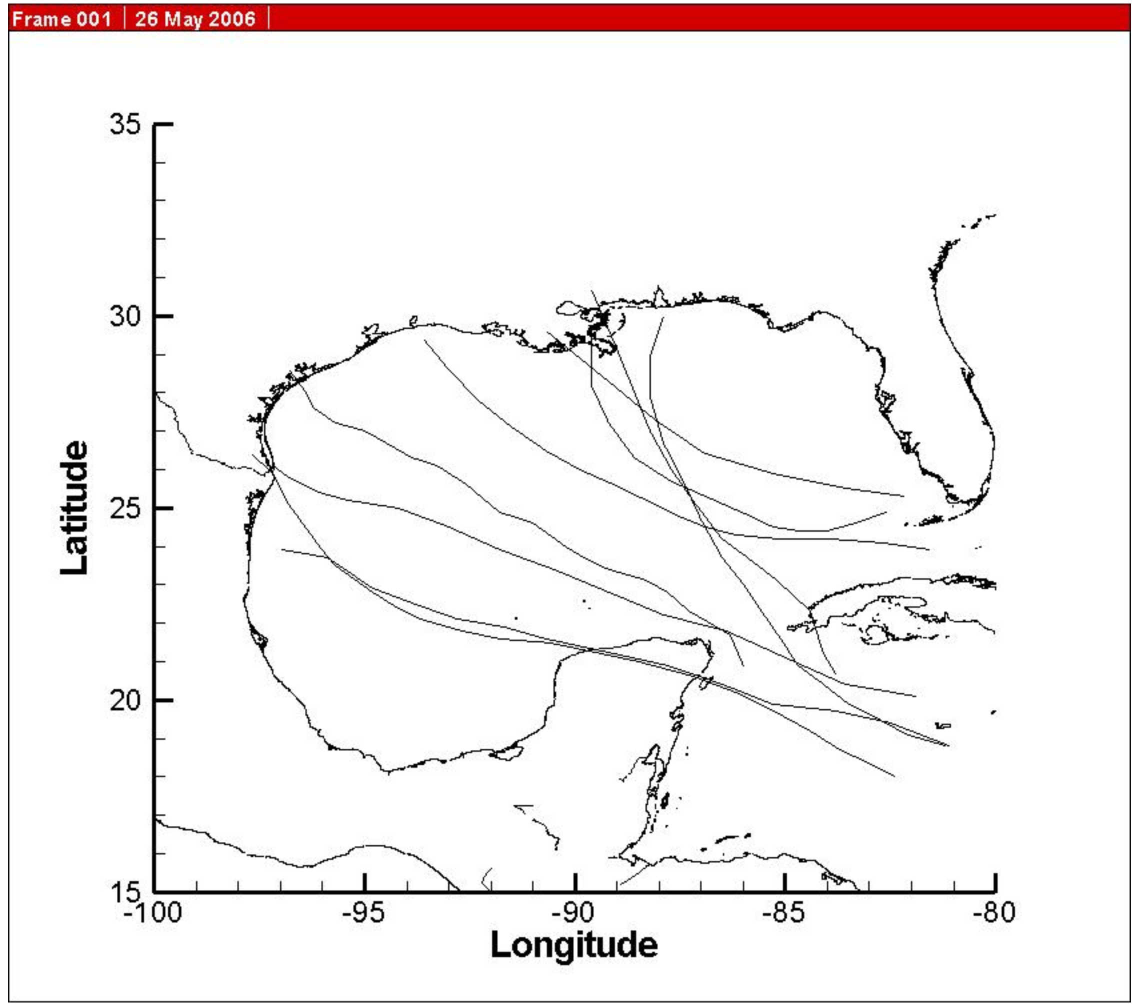
HURRICANE TRACKS FOR ALL STORM WITH VMAX ≥125 KTS

PHYSICAL CONSTRAINTS:

Land
Lack of Shear

Note:

Wilma, Charlie & Opal are west coast of Florida storms and will be under influence of westerlies



Given that there are only 6-9 strong storms in the entire record, isn't cutting this into 18000 slices for the JPM cutting the sample a bit thin?

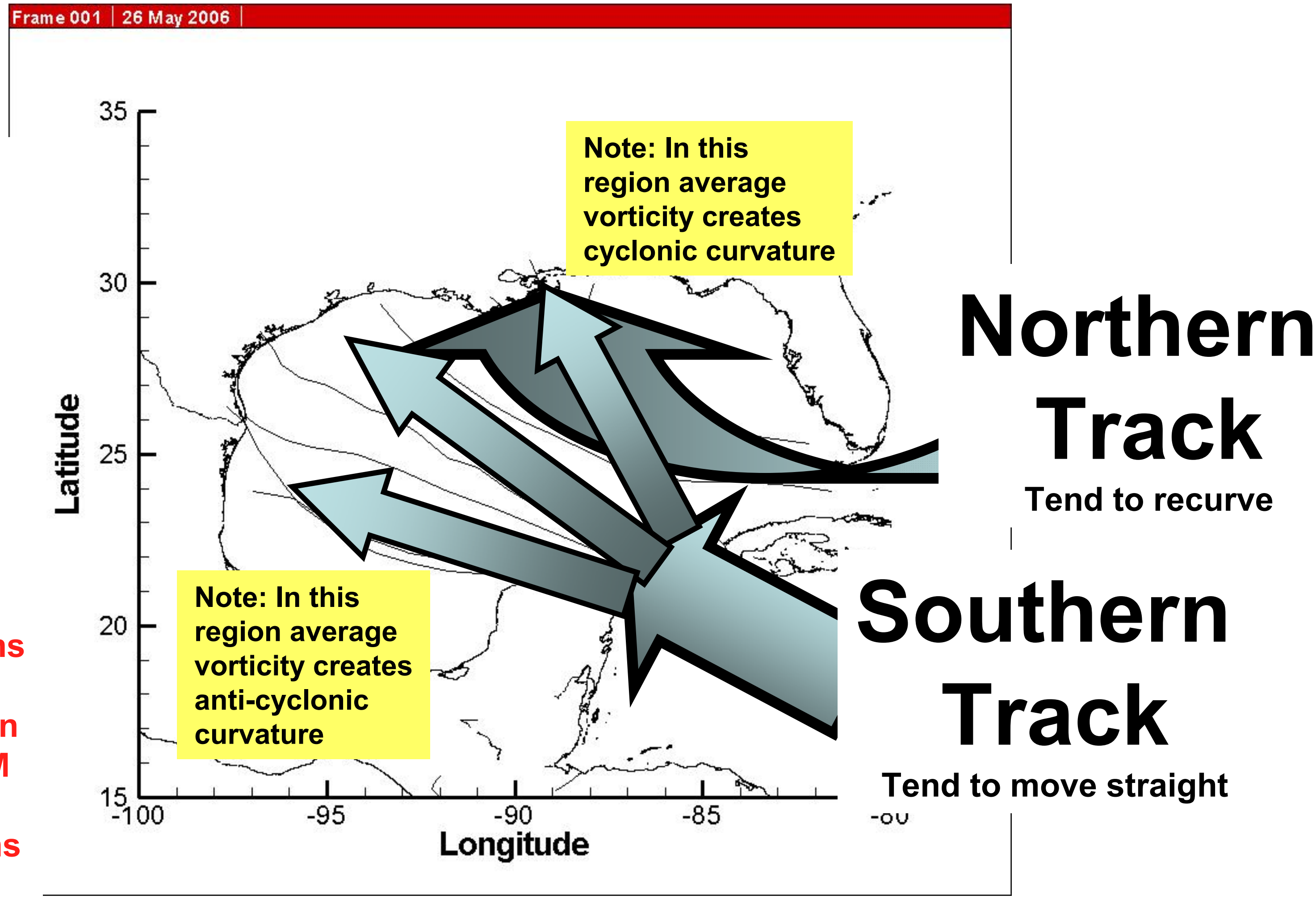
TWO PRIMARY "OVER-WATER" ROUTES INTO THE GULF OF MEXICO

These doors are wide open when the steering currents in the atmosphere and lack of shear in the Caribbean are in correct phase

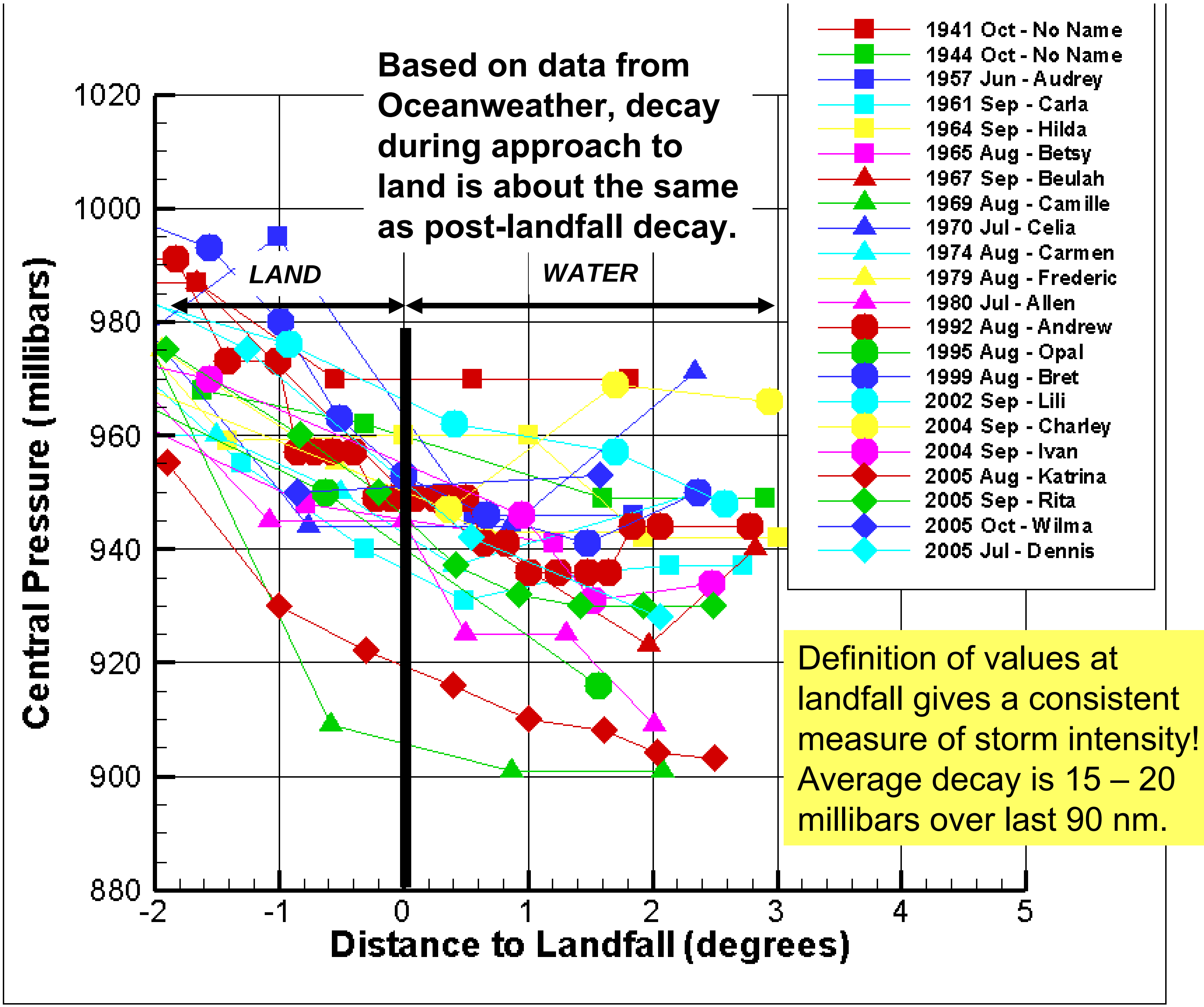
+

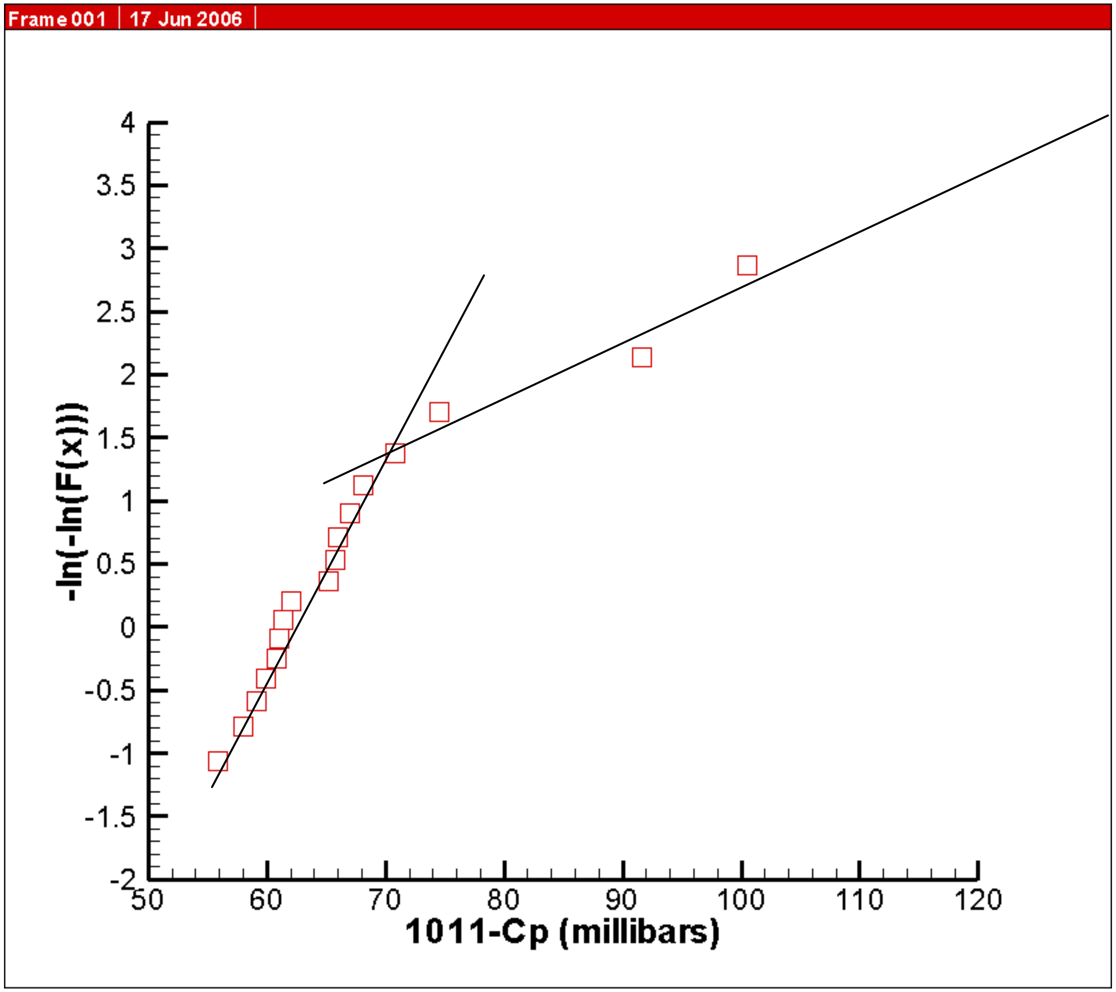
A warm Gulf of Mexico

NOTE: Small storms follow different patterns than shown here. Previous JPM studies have mixed small & large storms together to define angles of approach.



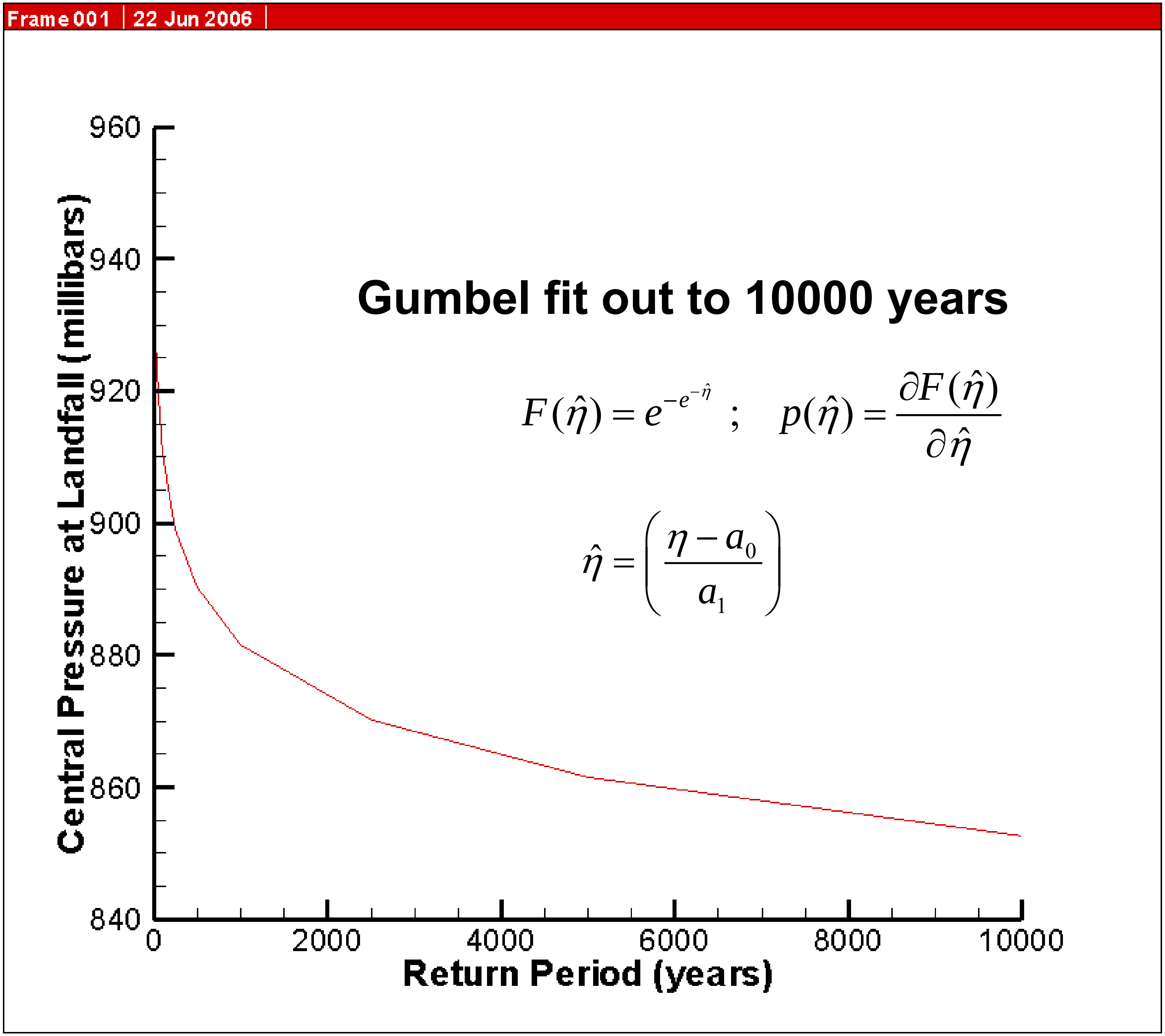
NOTE: These storms are not as curved as weaker storms since they are less controlled by extratropical influences. Also, statistics will likely be Gulf specific.


Based on data from Oceanweather, decay during approach to land is about the same as post-landfall decay.
LAND
WATER
Central Pressure (millibars)
1020
1000
980
960
940
920
900
880
-2
-1
0
1
2
3
4
5
Distance to Landfall (degrees)
1941 Oct - No Name
1944 Oct - No Name
1957 Jun - Audrey
1961 Sep - Carla
1964 Sep - Hilda
1965 Aug - Betsy
1967 Sep - Beulah
1969 Aug - Camille
1970 Jul - Celia
1974 Aug - Carmen
1979 Aug - Frederic
1980 Jul - Allen
1992 Aug - Andrew
1995 Aug - Opal
1999 Aug - Bret
2002 Sep - Lili
2004 Sep - Charley
2004 Sep - Ivan
2005 Aug - Katrina
2005 Sep - Rita
2005 Oct - Wilma
2005 Jul - Dennis
Definition of values at landfall gives a consistent measure of storm intensity! Average decay is 15 – 20 millibars over last 90 nm.



Gumbel plot suggests that, out of set of 22 storms, the largest 4 storms may represent a different population.

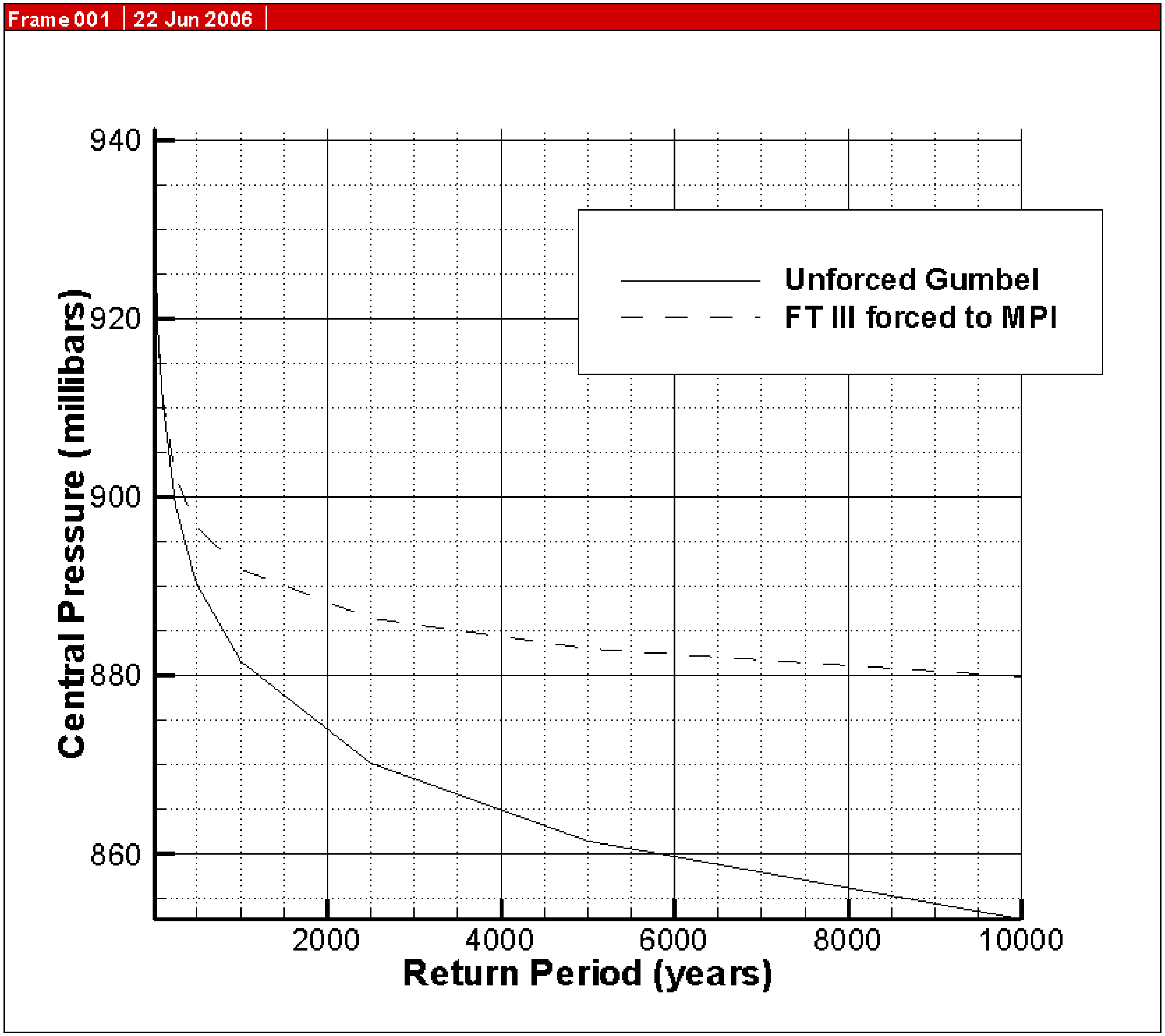
Plot of the cumulative distribution function for pressure difference from peripheral pressure (1011-Cp) versus pressure difference from peripheral pressure for all storms at landfall.



Gumbel fit out to 10000 years

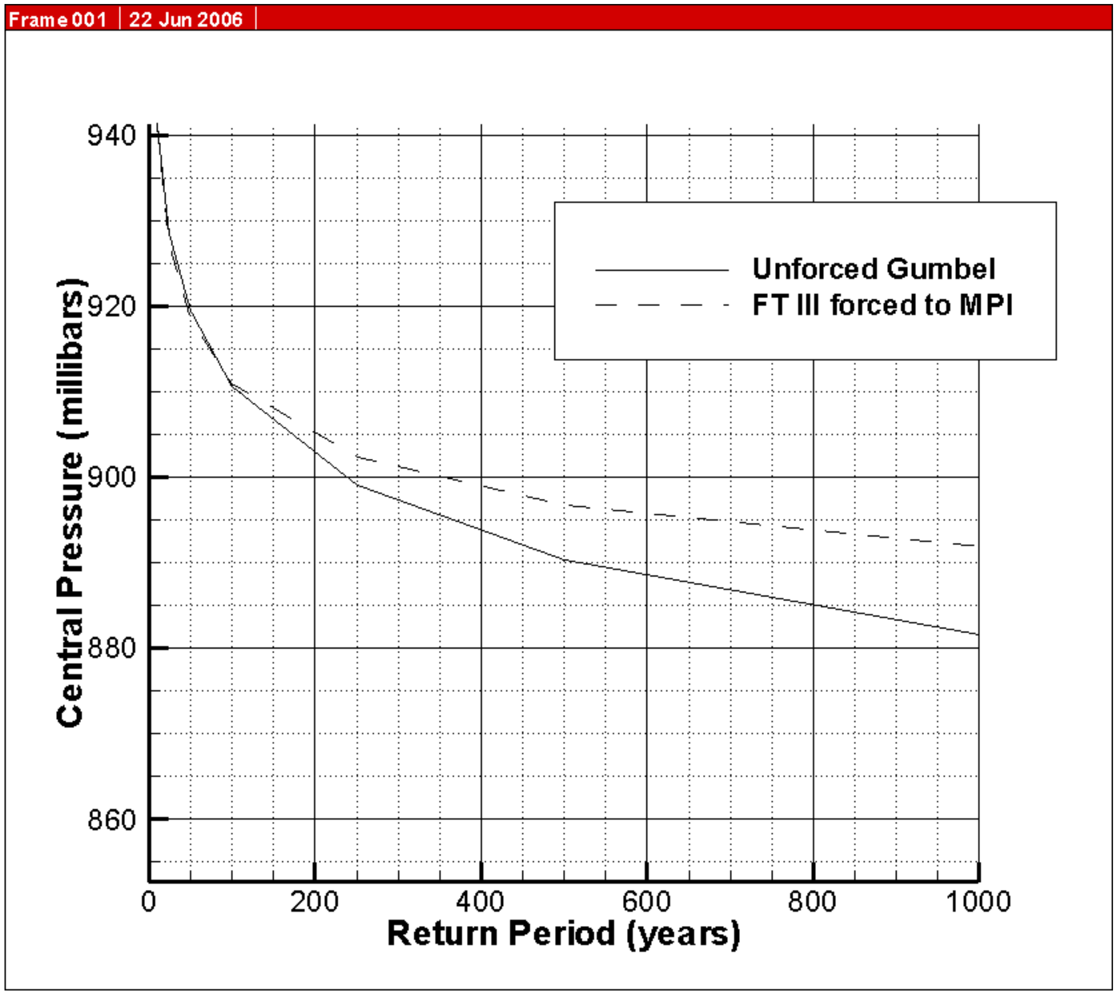
$$F(\hat{\eta}) = e^{-e^{-\hat{\eta}}} \quad ; \quad p(\hat{\eta}) = \frac{\partial F(\hat{\eta})}{\partial \hat{\eta}}$$

$$\hat{\eta} = \left(\frac{\eta - a_0}{a_1} \right)$$



Solving for the inverse GEV function such that the limit is equal to the MPI value of approximately 880 mb at 10000 years yields the solution shown here, with the Generalized GEV form given by

$$\hat{\eta} = b_0 + b_1\left(\frac{1 - e^{-b_2\eta}}{b_2}\right)$$



Same as previous derivation except that curve is only shown out to 1000 years.

We have shown that as a good approximation the peak surge can be written in Terms of a set a 4 parameters, holding the Holland "B" term constant, at least for relative ranking:

$$\eta_p = \Phi(\Delta p, R_{\max}, V_f, \alpha_f)$$

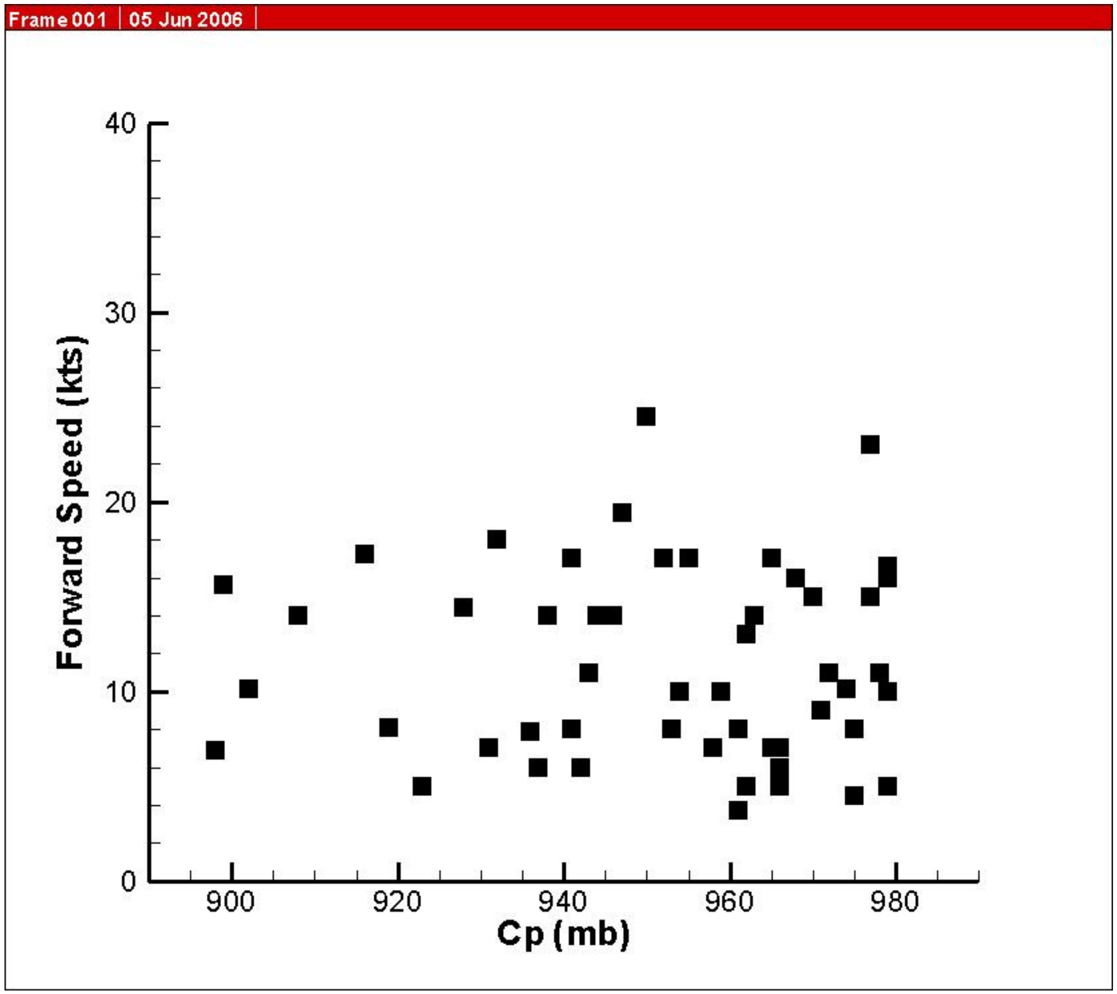
where α_f is the track angle relative to the coast. The probability of η_p is

$$p(\eta_p) = \iint p(\Delta p, R_{\max}, V_f, \alpha_f)\delta[\eta_p - \Phi(\Delta p, R_{\max}, V_f, \alpha_f)]d\Delta p dR_{\max} dV_f d\alpha_f$$

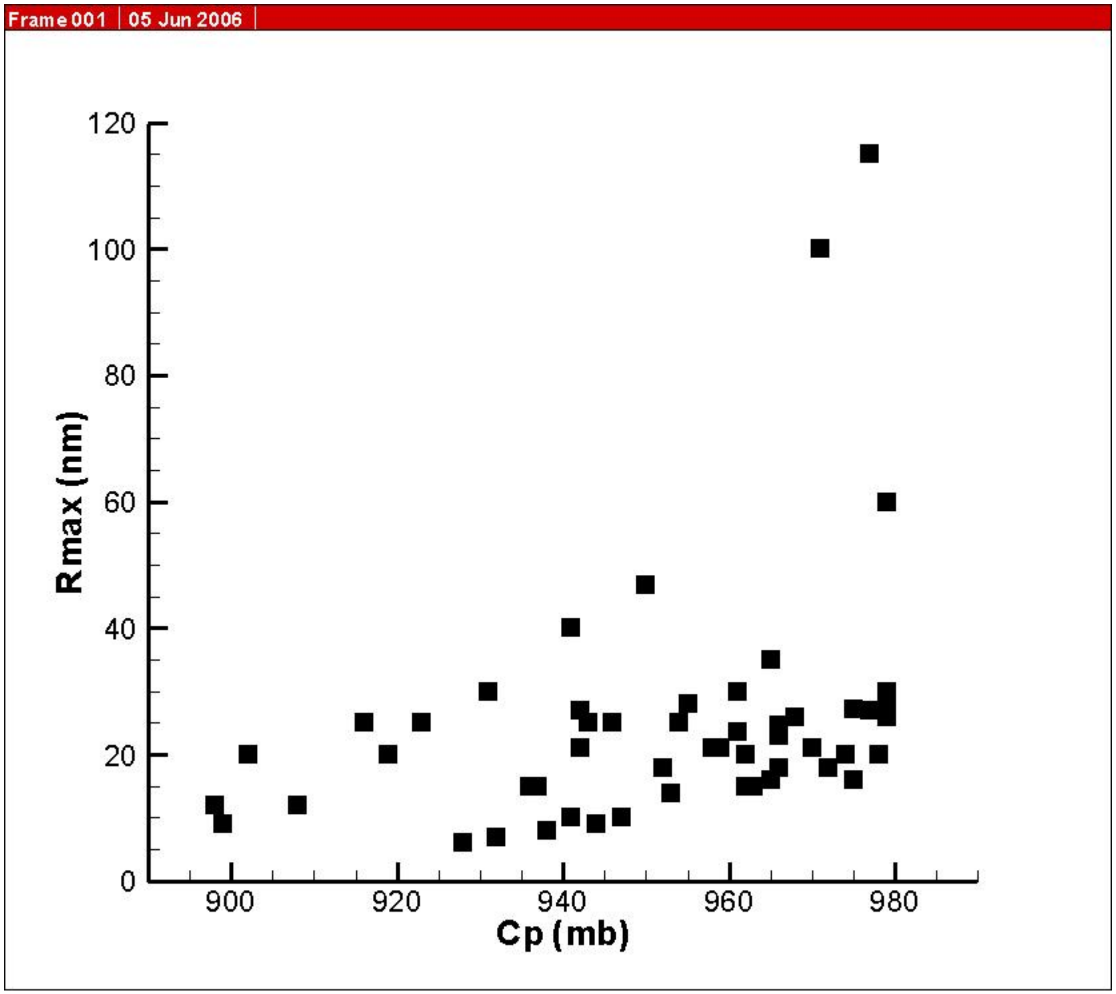
where δ[x] is the Dirac delta function {δ[x]=1 for x=0; =0 otherwise.
For a narrow distribution of track angles we can approximate this with a fixed angle and remove the integration over α_f

$$p(\eta_p) = \iint p(\Delta p, R_{\max}, V_f)\delta[\eta_p - \Phi(\Delta p, R_{\max}, V_f, \bar{\alpha}_f)d\Delta p dR_{\max} dV_f$$

We need to examine the characteristics of the multivariate distribution here.



Forward speed of storm appears independent of Cp



Rmax appears to have a functional dependence on Cp

Given the form of the relationship, it is advisable to use a conditional probability relationship for R_{max} to capture its dependence on Δp, i.e.

$$p(\eta_p) = \iint p(R_{\max} \mid \Delta p, V_f)\delta[\eta_p - \Phi(\Delta p, R_{\max}, V_f, \bar{\alpha}_f)d\Delta p dR_{\max} dV_f$$

Now we need to relate the surges at a fixed point to the distribution of maximum surges along a line.

The relationship between the local distribution of surges at a specific location, $p(\eta)$
and the joint probability of peak surges from an event and the alongshore distribution of the surges, $p(\eta_p, x)$
is given by

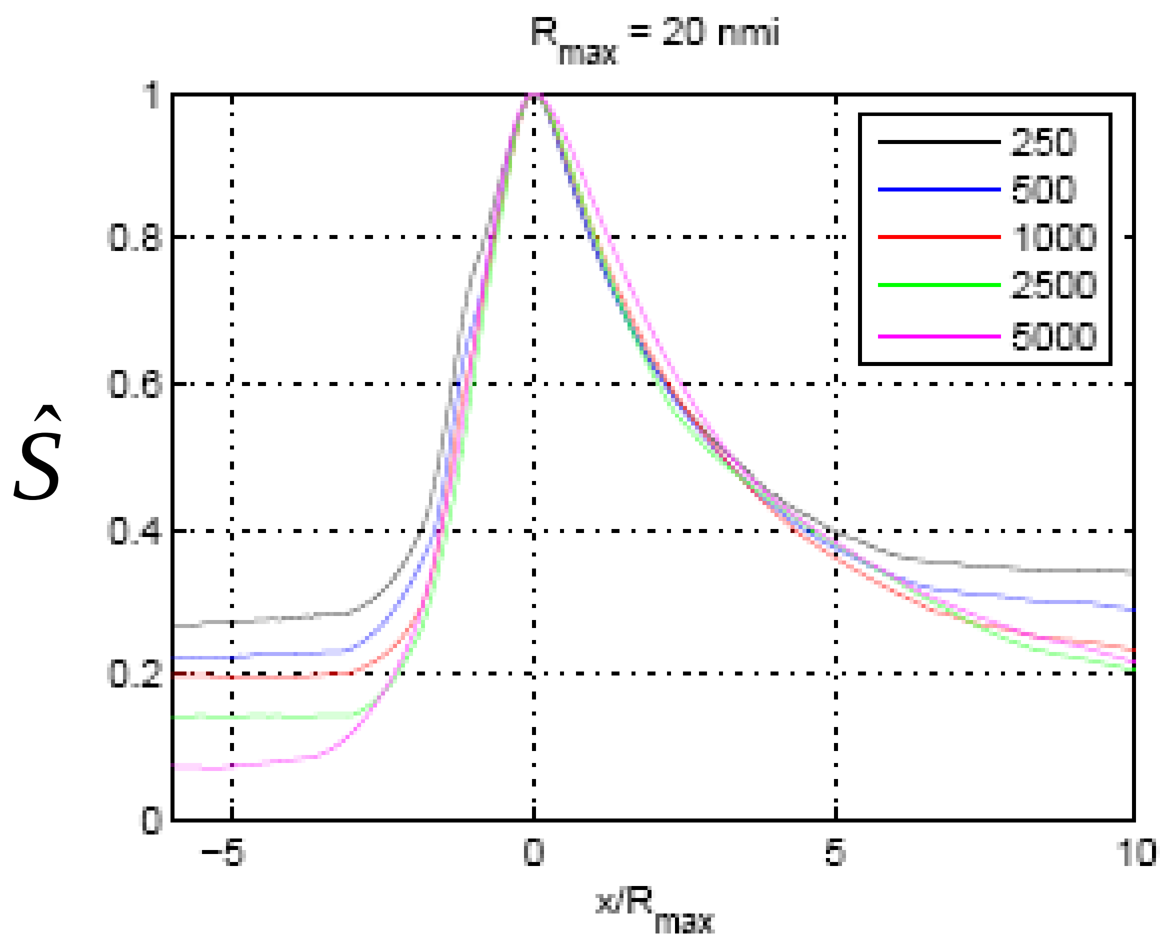
$$p(\eta) = \iint p(\eta_p, x)\delta[\eta - \psi(\eta_p, x)]dxd\eta_p$$

Where $\psi(\eta_p, x)$ is a spatial operator that relates the distribution of surge heights along the coast to the surge heights at a given location, x.

is the Dirac delta function, in which z is just an arbitrary real argument, $\delta(z)$ = 0 for z≠0; and =1 for z=0.
This function is related to the Heaviside function via the relationship

$$H(z) = \int_0^z \delta(z)dx$$

is the Dirac delta function, in which z is just an arbitrary real argument,
which is related to the Heaviside function via the relationship, H(z) = 0 for z<0; = 1 for z>0.



The nondimensional surge has an even more consistent shape as a function of nondimensional distance from the location of peak surge x/R_{max} for moderate storm sizes.

The definition of an equivalent time for an event of size η to occur at a specific site versus the same an event anywhere in the domain is given by the relationship

$$\lambda_e = \frac{T_R(\eta)}{T_R(\eta_p)}$$

For a Gumbel Distribution we have the classic double exponential form governed by

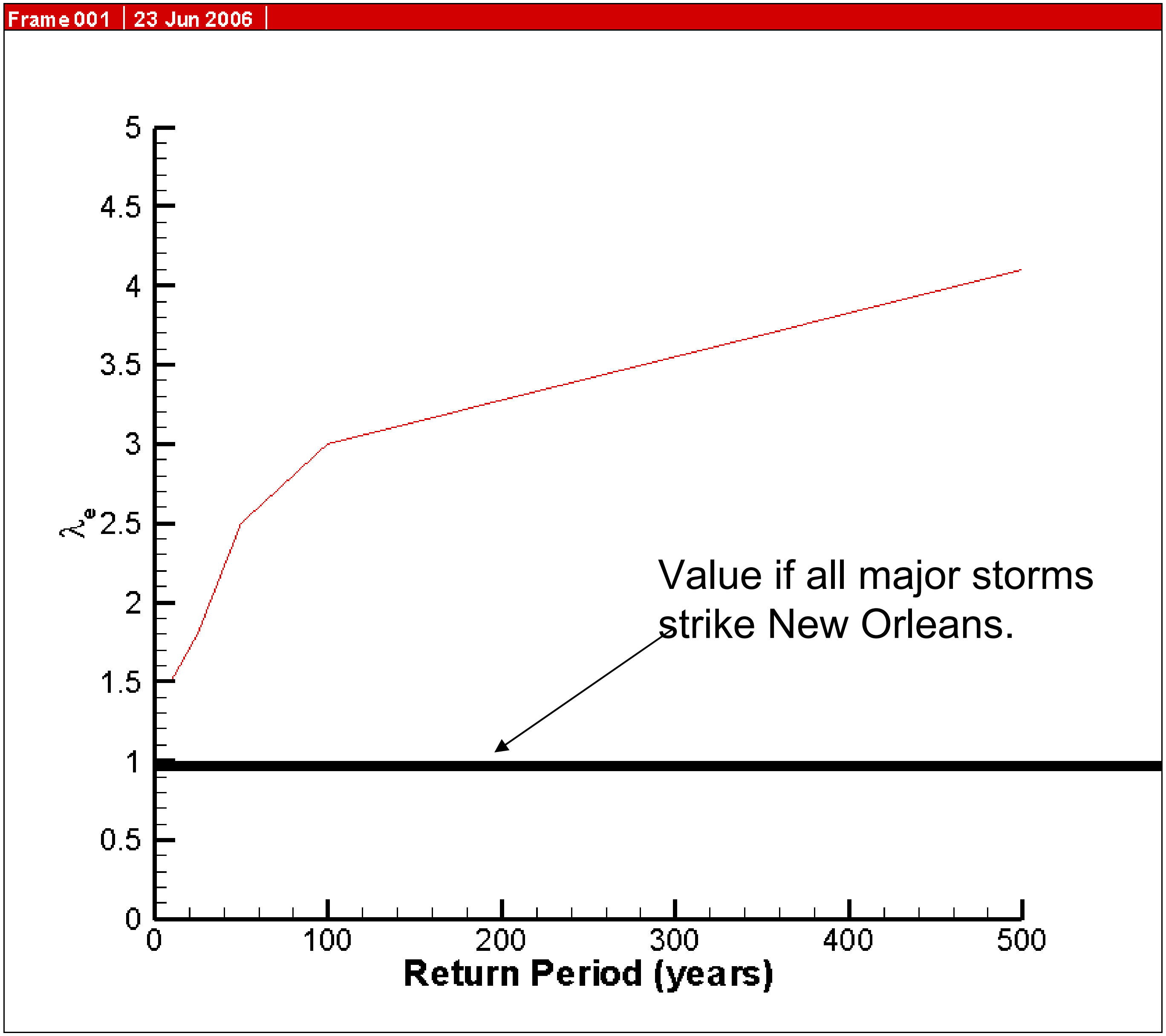
$$F(\hat{\eta}) = e^{-e^{-\hat{\eta}}} \quad ; \quad p(\hat{\eta}) = \frac{\partial F(\hat{\eta})}{\partial \hat{\eta}}$$

where

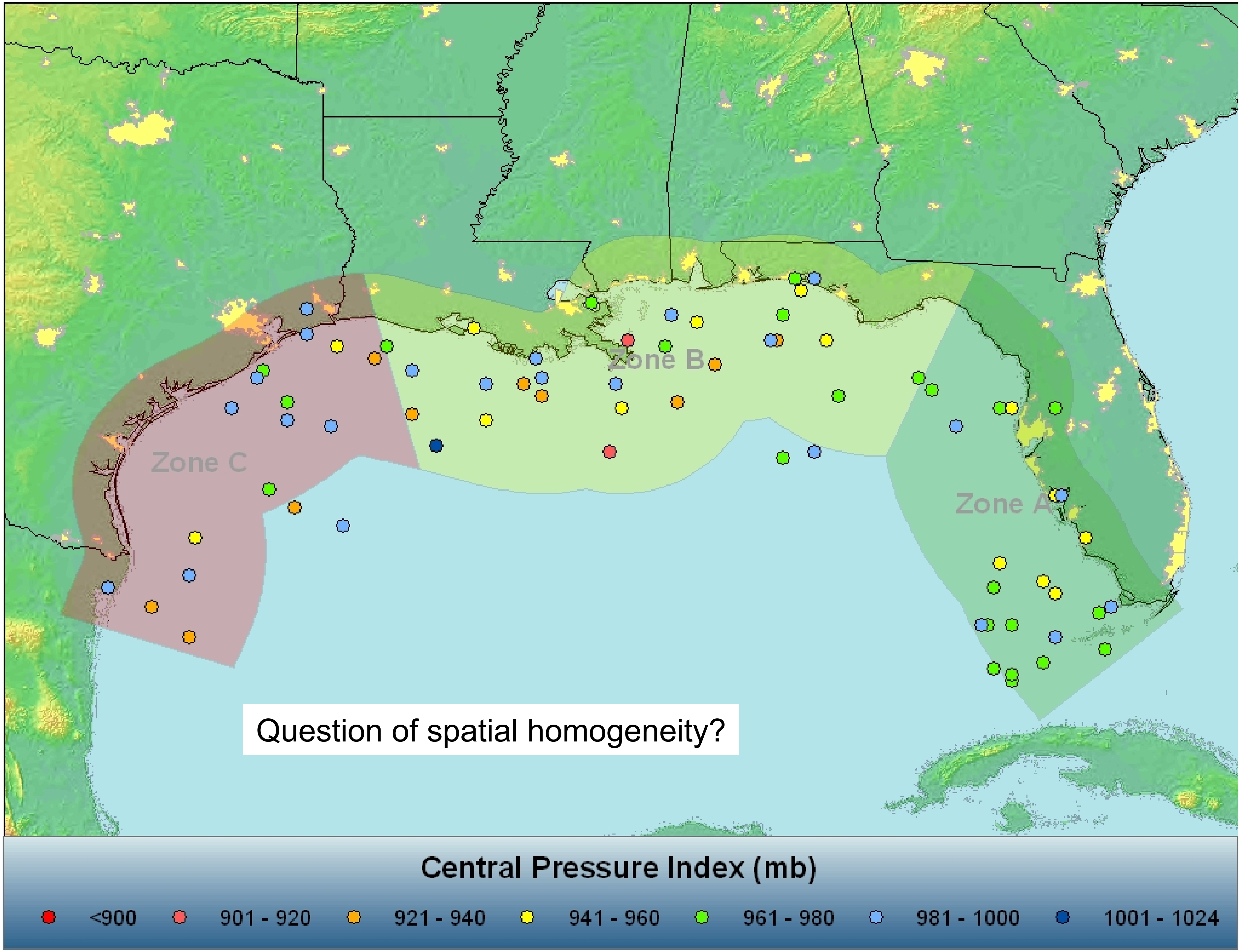
$$\hat{\eta} = \left(\frac{\eta - a_0}{a_1} \right)$$

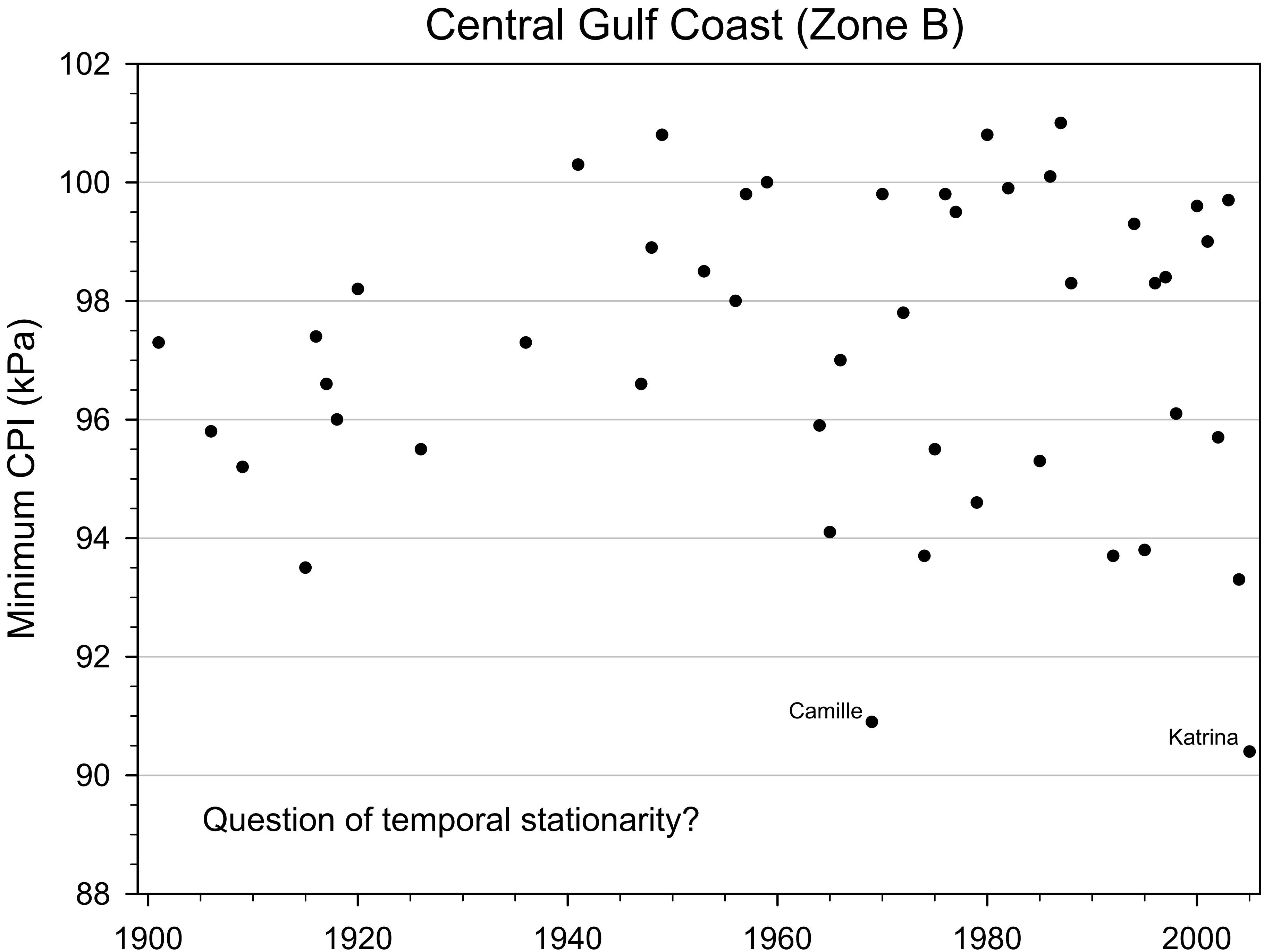
The 3-parameter distribution can be estimated via the generalized transform

$$\hat{\eta} = b_0 + b_1 \left(\frac{1 - e^{-b_2 \eta}}{b_2} \right)$$

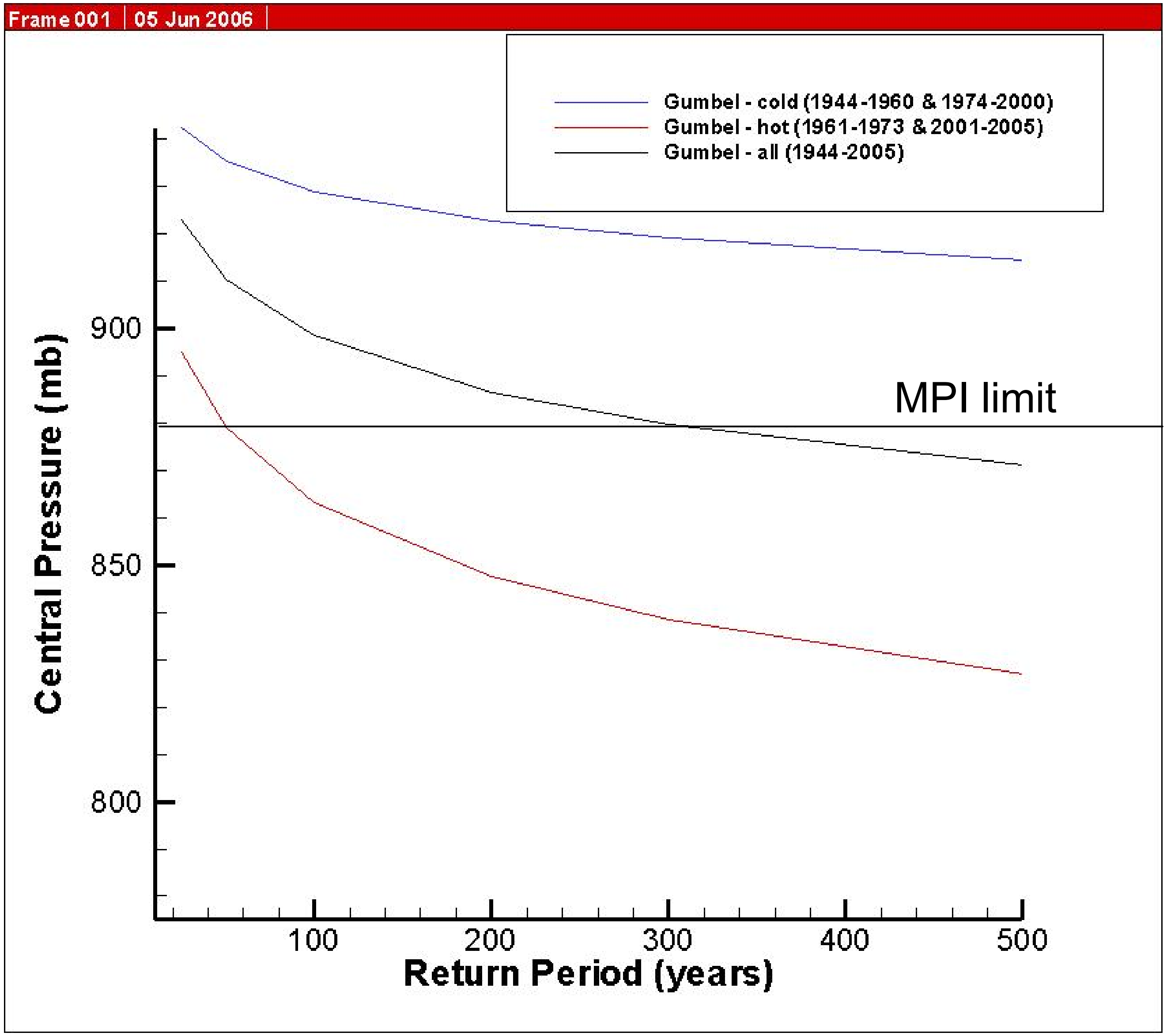


Interpretation: The largest 100-year surge within the entire 600 nm length of coast Included in this analysis would represent a 300-year surge at a fixed location- if the area is considered homogeneous.


Zone C
Zone B
Zone A
Question of spatial homogeneity?
Central Pressure Index (mb)
<900
901 - 920
921 - 940
941 - 960
961 - 980
981 - 1000
1001 - 1024



Central Gulf Coast (Zone B)
Minimum CPI (kPa)
102
100
98
96
94
92
90
88
1900
1920
1940
1960
1980
2000
Camille
Katrina
Question of temporal stationarity?



Subdividing time indicates that both frequency and intensity of storms increases
During favorable years versus unfavorable years.

Some preliminary findings:

Angle range is probably much smaller than assumed in JPM

Forward velocity of around 11 knots should suffice to
represent storm surge for most of this area

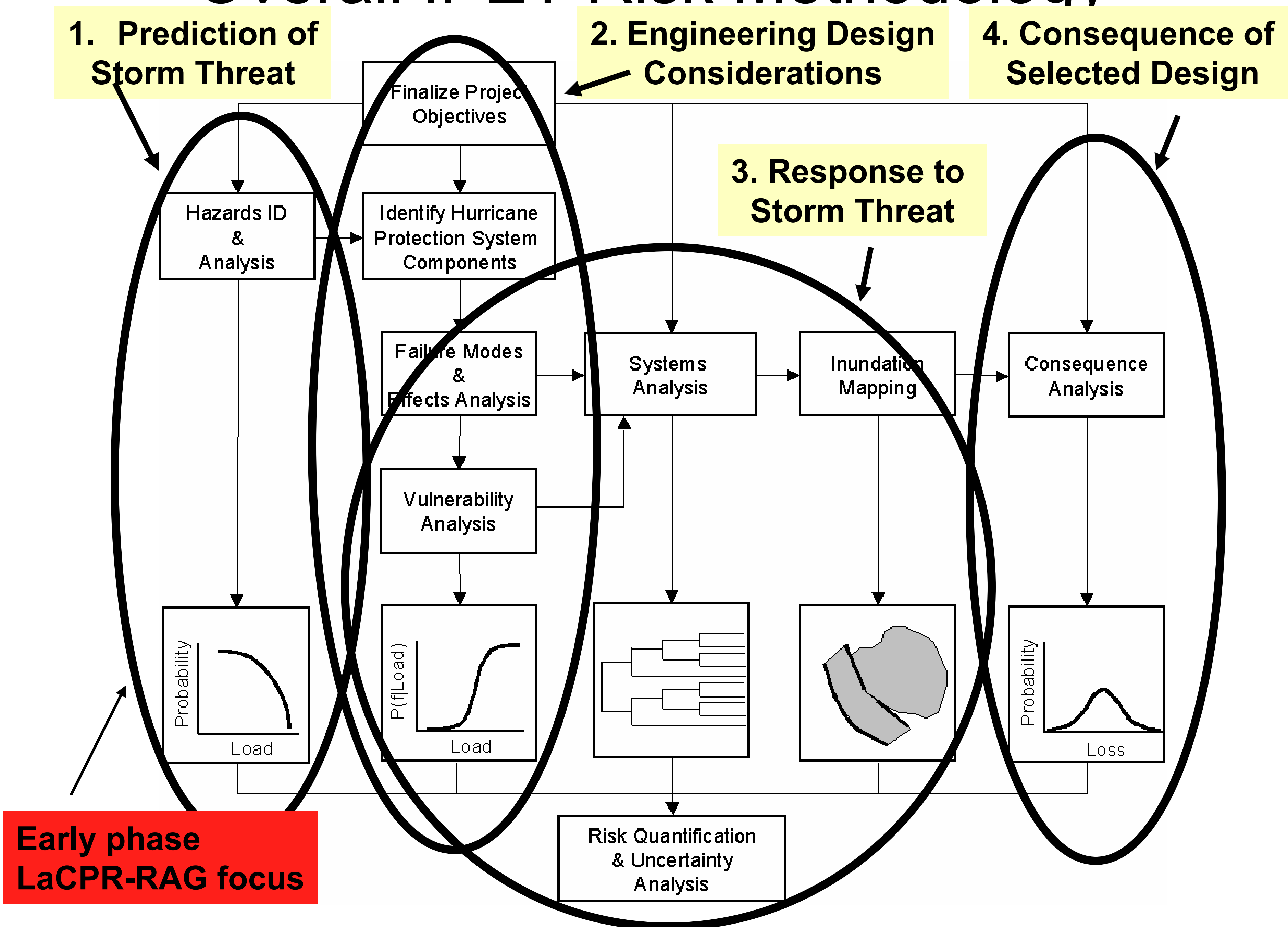
Curvature is fairly small for large storms

This leaves only Rmax and Cp as the primary variables –
along with decay during approach to coast and
proper specification of wind field and waves

Rmax and Cp cannot be treated as independent

For a specified risk level, selection of appropriate Rmax-Cp combinations may yield a sensible screening storm set

Overall IPET Risk Methodology



RISK ASSESSMENT FINDINGS:

Accuracy of estimates depends on getting the "details" right

Storm decay during approach to coast is significant

Large storms cannot be predicted via carte blanch analysis of all storms

Set of "screening" storms has been delivered for initial analysis of design alternatives

FUTURE DIRECTIONS

Complete careful analysis of surge probabilities for present system – compare to FEMA results

Complete careful analysis of surge probabilities for selected hurricane protection systems


QUESTIONS??